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# A STUDY OF SOME PHYSICAL AND CHEMICAL ENVIRONMENTAL FEATURES OF A LARGE SEWAGE OXIDATION POND. PART I

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Humboldt State College
Arcata, California

30 April 1967

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# A STUDY OF SOME PHYSICAL AND CHEMICAL ENVIRONMENTAL FEATURES OF A LARGE SEWAGE OXIDATION POND

by

Richard J. Hansen
and
John W. DeWitt

PART I

Of Final Report on Project

Improvement of Oxidation Pond Effluents by Organisms

Public Health Service

Research Grant, RG-6691

John W. DeWitt, Ph.D.
Principal Investigator

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# INTRODUCTION

A project was initiated in 1959 to survey sewage oxidation ponds in north coastal California.[1] The primary purpose of the project was to determine the feasibility of producing fish and other organisms in a large oxidation pond to improve the efficiency of the waste treatment process and to provide a means of converting waste materials into useful and retrievable forms. A secondary goal of the project was to provide general information on the performance of sewage oxidation ponds in a temperate, maritime climate.

Specifically, this report is based on an analysis of chemical and physical data and observations collected at the Arcata, California sewage oxidation pond during the period July, 1959, through November, 1961. The basic objectives of this segment of the project were:

1. To characterize the chemical and physical features of the oxidation pond with respect to prevailing climatic and operational conditions.

2. To determine waste treatment performance prior to manipulation of the oxidation pond's flora and fauna. The features studied were mainly those that were expected to be most important in providing a background for assessing

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[1] Study conducted by Humboldt State College under the direction of Dr. John DeWitt with support from National Institutes of Health Research Grant, RG-6681 (C1).

changes in the pond caused by the introduction of fish and other organisms, and the manipulation of their numbers or by adjustments in the overall management of the pond; and

3. To evaluate the suitability of the oxidation pond for the production of fishes.

A survey of the literature reveals that in the years following the second world war the sewage oxidation pond has gained widespread acceptance as a method of domestic waste treatment. The acceptance of oxidation ponds is largely attributed to the fact that they are simple and inexpensive to construct, maintain and operate, as well as being effective in the treatment of sewage. Investigations have shown that this type of treatment facility is capable of operating successfully over a wide range of climatic and design conditions. For example, oxidation ponds have been used in Sweden (Wennstrom, 1949), Australia (Parker, et al., 1959), Canada (Voege and Stanley, 1963), Israel (Watson, 1963) and in the United States where they have been approved for use in 41 states and 1,647 municipalities (Porges and Mackenthun, 1963). The development, performance and distribution of sewage oxidation ponds in the United States have been described and discussed by Caldwell (1946), Davis (1955), Fitzgerald and Rohlich (1958), Smallhorst (1959), Webber (1959), Smith (1960), Mackenthun and McNabb (1961), and others.

Sewage oxidation ponds function by detaining raw or partially treated sewage for the purpose of improving some features of the waste. Stabilization is one of the main

processes involved in the improvement. Studies by Ludwig and Oswald (1952), Silva and Papenfuss (1953), Gotaas, et al. (1954a), Oswald and Gotaas (1955) and Loedolff (1964) have shown that stabilization of sewage in oxidation ponds is similar in nature to the natural purification of rivers and streams. The stabilization mechanism consists of mutual beneficial interactions among bacteria, algae and various other micro-organisms. These interactions result principally in the conversion of relatively unstable organic matter to more stable forms such as algal cell material and protoplasm of higher organisms. Thus, organic wastes are transformed into less active and often less objectionable forms.

Bacteria convert the organic matter in sewage to carbon dioxide, ammonia and other algal growth essentials. Algae, through photosynthesis, transform these essentials into cell material, liberating oxygen as a by-product. The oxygen helps to develop and maintain a suitable environment for the aerobic bacteria that are required for the breakdown of wastes without production of offensive odors. Although organic wastes in oxidation ponds can be and are stabilized to some extent under anaerobic conditions, too much of this form of decomposition is discouraged because of the obnoxious odors that accompany such reactions and because complete stabilization does not occur under these conditions.

Although of secondary importance in the overall stabilization process, certain micro-invertebrates play an

important role. The Cladocera, for example, aid in the flocculation of algal cell material and other suspended particulate matter through their feeding mechanisms. Other micro-invertebrates provide a similar function. Even though these organisms may die and settle within the confines of a pond, their effect on organic loading of a receiving water is less than that of the algae and other organic matter upon which their production was based (Wennstrom, 1955).

Perhaps the most unique advantage of the oxidation pond method of waste treatment is that the ponds are a potential source of valuable nutrients (Ludwig, et al., 1952; Allen, 1955; Isaac and Lodge, 1958). For the most part these nutrients are incorporated in the cellular structure of oxidation pond algae. With proper technology and manipulation the algae could be harvested and the nutrients reclaimed and utilized.

Although nutrient reclamation is a prime consideration there is another important reason for harvesting oxidation pond algae. Under certain situations failure to remove the algal mass may cause the ponds to lose much of their value as a waste treatment device (Gotaas, et al., 1954b). For example, in ponds having long detention periods there is evidence that the respiratory requirements of the algal mass surpass the biochemical oxygen demand in the original sewage (Bartsch, 1961). Consequently, the discharge of large masses of decomposing algal material could place an excessive burden on the oxygen resources of a receiving water.

It would appear, therefore, that there are three good reasons to remove algal masses from oxidation ponds.

1. To recover valuable nutrients.
2. To maintain the highest degree of treatment.
3. To protect the oxygen reserves of receiving waters.

Due largely to lack of suitable techniques, harvesting of algal cell material from oxidation ponds has not been very successful. Since the early nineteen fifties several methods have been proposed and tested. The most frequently referred to in the literature are screening, settling, centrifuging and chemical coagulation (Steel and Gloyna, 1954; Golueke and Gotaas, 1957; Golueke, et al., 1958; Golueke et al., 1964; and Golueke and Oswald, 1965). All methods have been found wanting in some aspect, generally in terms of efficiency and often in terms of cost.

Indirect harvesting of oxidation pond algae in the form of fish flesh may prove to be a practical and economical approach to reclaiming nutrients of sewage origin. This concept envisions oxidation ponds merely as highly fertilized bodies of water in which rates of fish production can be high. The potential for producing fish in such ponds has not been exploited to a great degree partly because the ponds are not ordinarily designed to be suitable for the production of fishes. In most cases, pond sizes have been too small for the loads of sewage received. Under such circumstances, the extremes in chemical conditions which occur usually render these ponds unsuitable even for coarse fishes.

For example, dissolved oxygen levels have been known to fluctuate from zero to 35 mg/l within a single 24-hour time span (Bartsch and Allum, 1957). In a detailed study of chemical and physical properties existing in a series of oxidation ponds located at Fayette, Missouri, Neel et al., (1961) showed that ammonia nitrogen concentrations sometimes approached 15 mg/l when pH values exceeded 10. These conditions would preclude survival of most species of fishes.

Under certain conditions, however, fishes can be reared successfully in sewage oxidation ponds. For example, fishes have been cultured in such ponds in Germany since the turn of the century (Kisskalt and Ilzhofer, 1937). Within recent years fishes have been cultured in oxidation ponds in Sweden (Wennstrom, 1955), Israel (Watson, 1963) and at Santee, California (Merrill, 1964). The successes of these operations were gained largely through construction of a series of small ponds in which conditions were suitable for fishes in at least one pond in the series.

# II DESCRIPTION OF STUDY AREA

## Geographic Location

The investigation was conducted at the oxidation pond of the City of Arcata, Humboldt County, California. Arcata is situated on the coast approximately 290 miles north of San Francisco at the northeast end of Humboldt Bay (Figure 1).

## Climatological Features

### General

The Humboldt bay region has a climate characterized by high humidity and moderate temperatures throughout the year. Generally, the region has two seasons. The "wet" season commences in October and continues through mid-May. Approximately 95 per cent of the normal 39.49-inch rainfall occurs during this time (U. S. Weather Bureau station, Eureka, Calif.). The "dry" season extends from May through September and is characterized by considerable morning and evening fog or low cloudiness with some clearing generally during mid-morning and afternoon. During the year approximately 75 per cent of the days are cloudy or partly cloudy.

The annual temperature ranges from about 35°F. to 75°F. The diurnal range averages about 9°F. during the summer and 13°F. in the winter.

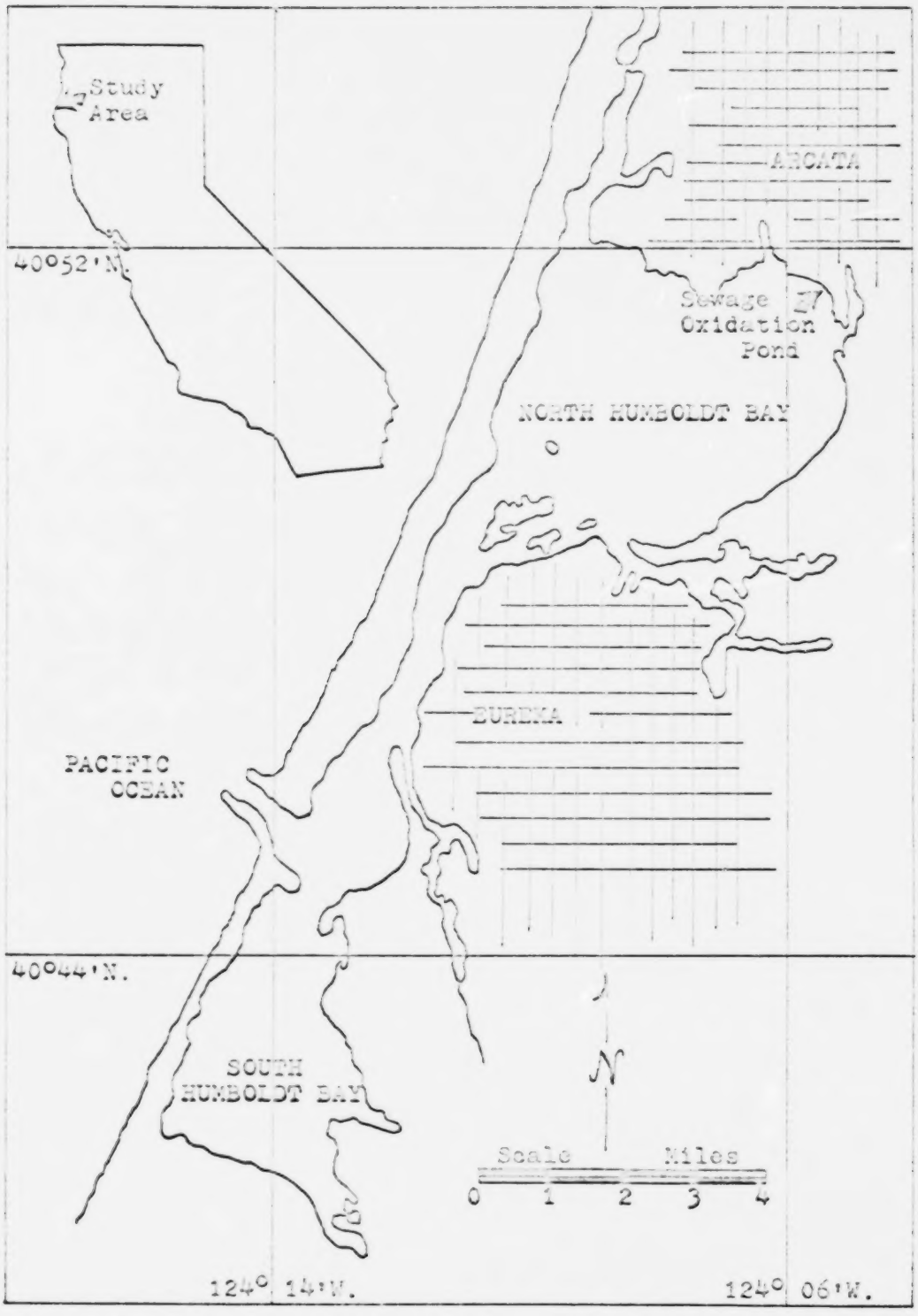



Figure 1.--Map of Humboldt Bay area showing location of Arcata sewage oxidation pond.

The prevailing winds are from the north; and their annual average velocity is 6.8 m.p.h. Velocities exceeding 40 m.p.h. are not unusual. Diurnally, the wind follows a generally similar pattern throughout the year. Calm conditions normally prevail until late morning whereupon the velocity gradually increases until late afternoon and then gradually subsides. The late evenings usually are calm.

During Study Period

Monthly summaries of climatological data compiled during the study period are given in Appendix A. The data are based on records maintained by the U. S. Weather Bureau station located in Eureka approximately 8 miles south of Arcata. Long term (29-63 year) record mean values of some features are included for comparison with values observed during the study period.

The warmest month on record, as indicated by a maximum mean monthly temperature of 57.8°F., was September, 1959. The coldest month, as indicated by a minimum mean temperature of 47.5°F., was December, 1959. The highest and lowest daily temperatures were 77°F. (on October 16, 1960) and 30°F. (on January 1, 1960), respectively. The maximum and minimum mean monthly ranges were 14.4°F. (January, 1961) and 8.0°F. (July, 1960), respectively. Diurnal variations ranged from a minimum of 14°F. (on July 12, 1960 and July 11, 1961) to a maximum of 30°F. (on November 26, 1959).

During the 24-month study period, total precipitation was 79.24 inches. Of this approximately 97 per cent occurred

between the months of October and May. March was the wettest and July was the driest.

The prevailing winds during the latter part of 1959 through 1960 were from the north at a mean speed of 6.4 m.p.h. The calmest months were from February through May. The highest wind velocity recorded was 48 m.p.h. (on February 8, 1960).

The percentage of sunny hours out of the total number possible ranged from 30 (March, 1960) to 69 (April, 1961). The mean value for the study period was 49.9.

## The Primary Sewage Treatment Facilities

The initial units of the primary treatment facilities were constructed in 1949, at which time the sewered population was estimated to be 3,700. In 1958 the facilities were expanded to handle the wastes of a maximum population of 15,000.

The primary facilities consist of a headworks structure, pumping station, aerator, primary clarifier, sludge digestion system and a control building (Figure 2). After passing through the headworks structure, the influent is pumped to the aeration unit and then carried by gravity flow to the clarifier. Some of the solids are removed in the clarifier and pumped to the digesters to undergo anaerobic decomposition. Periodically, sludge is removed from the secondary digester, dried and then used for fertilizer. Following clarification, the supernatant from the clarifier flows by gravity into the oxidation pond.

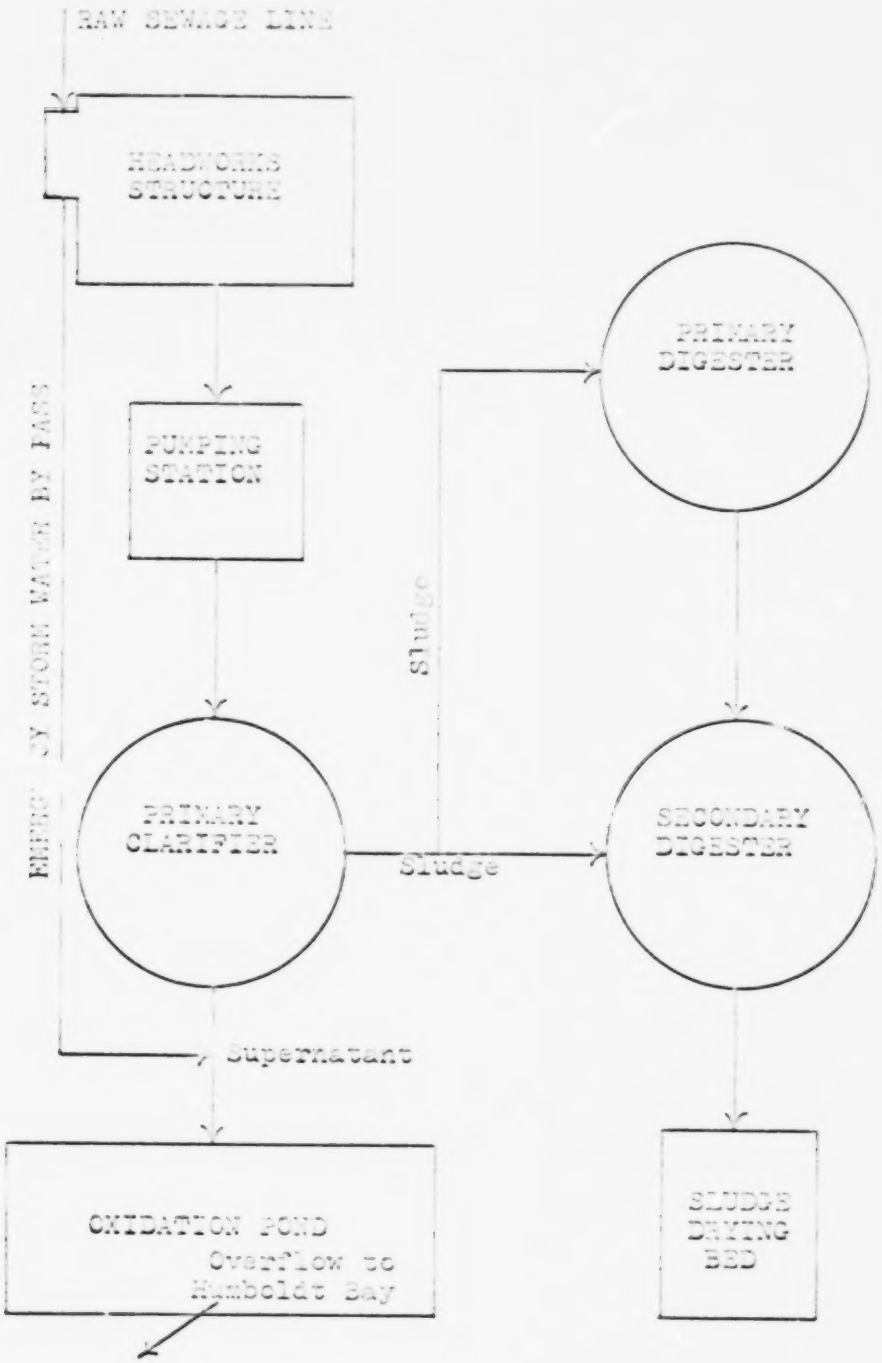



Figure 2.--Schematic flow diagram of the sewage treatment facilities at Arcata, California.

During storms, ground-water infiltrates the sewage collection system and thereby increases the flow to the treatment plant. As a consequence the combined flows often exceed the normal pumping capacity of the plant. Under such conditions the excess flow is diverted without treatment directly to the oxidation pond.

## The Oxidation Pond

The oxidation pond was constructed in 1957 as an integral unit of the expanded sewage treatment facilities. It was designed for secondary treatment to serve a maximum of 254 persons per surface acre. The pond is located on the tide flats southeast and adjacent to the treatment plant (Figure 1). A mud dike, constructed of materials dredged from the bay, forms the perimeter of the pond (Figure 3). The bottom consists primarily of clay and tidal flat muck.

Surface acreages and corresponding pond volumes for different operating pond water levels are given in Table 1. Pond elevations are referred to mean lower low sea level. At the normal operating level of 6.5 feet elevation the surface area of the pond is 59 acres. The mean depth of the pond is approximately 3 feet with the exception of the 6 to 8 foot deep borrow trench which lies adjacent to the perimeter dike.

The clarifier effluent enters the pond from a submerged pipe at a point approximately 25 yards from shore. A flap-gate on the pond outlet pipe prevents bay water from entering the pond.

Table 1.--Surface acreages and corresponding volumes for different operating levels in the sewage oxidation pond, Arcata, California.[1/]

| Elevation of Water Surface[2/] in feet | Surface Acres | Volume Acre-feet | Volume Gallons |
|---|---|---|---|
| 3.0 | 16.5 | -- | -- |
| 4.0 | 45.2 | 75.4 | 24,600,000 |
| 5.0 | 58.0 | 127.9 | 40,300,000 |
| 6.5 | 59.0 | 260.0 | 84,600,000 |
| 7.0 | 59.3 | 289.0 | 94,200,000 |

1/ Data from City of Arcata, Department of Public Works, 1959.
2/ Elevation referred to U.S. Coast and Geodetic Zero (mean lower low sea level).

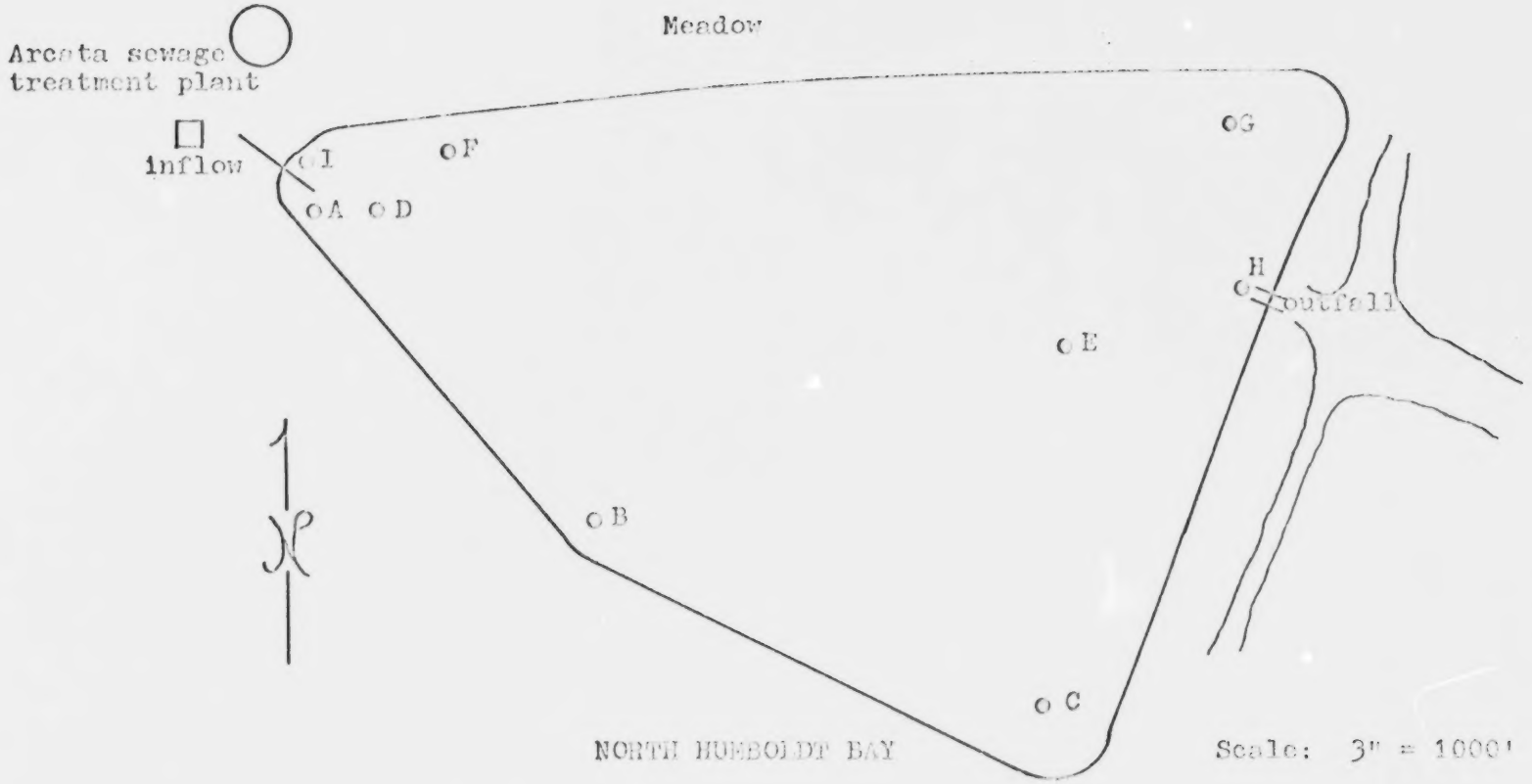



Figure 3.--General shape of the sewage oxidation pond and location of sampling stations, Arcata, California.

# III THE POND INFLUENT

## Sources and General Nature

The 1960 sewered population served by the Arcata sewage treatment facilities was estimated to be approximately 9,000. This figure includes the 2,000 students who were enrolled at Humboldt State College during the 1960-1961 academic year.

In addition to domestic sewage, some industrial wastes, including glue from plywood and pressed chipboard mills, enter the sewage system. Other industrial wastes include vegetable matter from supermarkets and petroleum products from service stations and automotive repair shops. Occasionally, septic tank wastes are deposited into the collection system.

## Volumes of Flow

### Measurement

Flows to the Arcata pond are herein considered to be equal to the metered flows entering the primary treatment facilities. However, during heavy storms because of accretions of rain water, flows to the pond are often greater than metered flows. Flows in excess of 3,000 gallons per minute (g.p.m.) are by-passed to the pond without being metered.

Diurnal Pattern

The diurnal pattern of flow exhibits the same characteristics regardless of the volume of water entering the pond. To demonstrate this, examples were selected from both wet (December 8, 1960) and dry (August 30, 1960) seasons (Figure 4). Both curves show that the major peak (maximum flow) is reached at noon and a secondary peak is reached at 2000 hours. The minimum flow occurs between 0400 and 0700 hours. The differences between the two curves is attributed to ground water infiltration. Because ground water infiltration is essentially non-existant during the summer, the bottom curve probably represents the "true" diurnal sewage inflow.

Weekly Pattern

During the dry season a consistent weekly pattern of daily flows to the Arcata sewage treatment facilities was evident. The flows to the Arcata plant during the week of August 28 through September 3, 1960, are typical of the pattern (Figure 5). Peak flows generally occur on Mondays and Fridays whereas low flows generally prevail during the weekends. During the wet season this pattern is not readily evident since it is masked by changing rates of ground water infiltration.

Seasonal Pattern

Metered flows ranged from a minimum of 0.342 m.g.d. (on July 3, 1960) to a maximum of 5.514 m.g.d. (on February 13, 1961). The maximum flow occurred following a 9-day period of rainfall in which 5.39 inches fell.

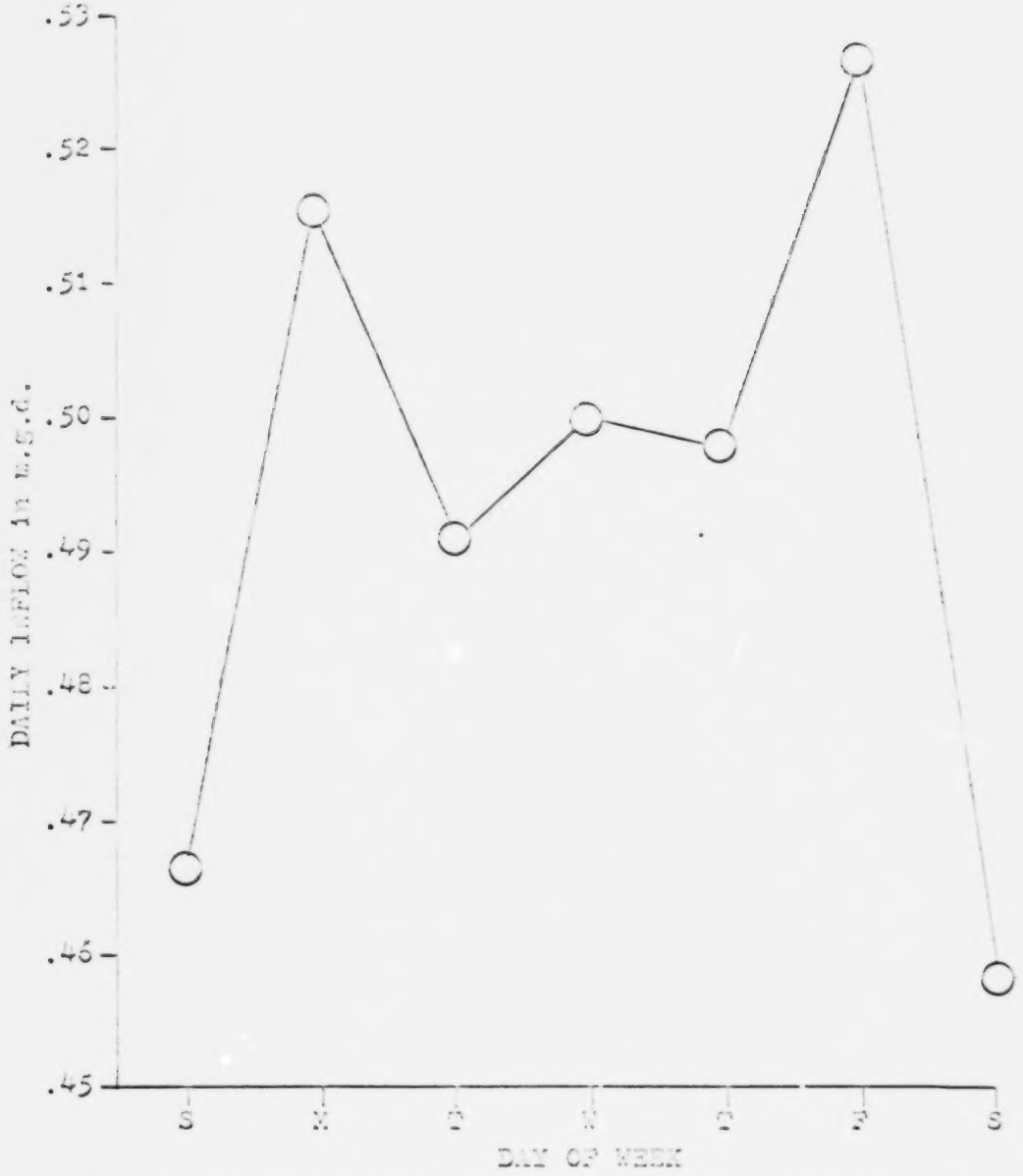



Figure 5.--General pattern of weekly sewage flows to the sewage oxidation pond, Arcata, California.

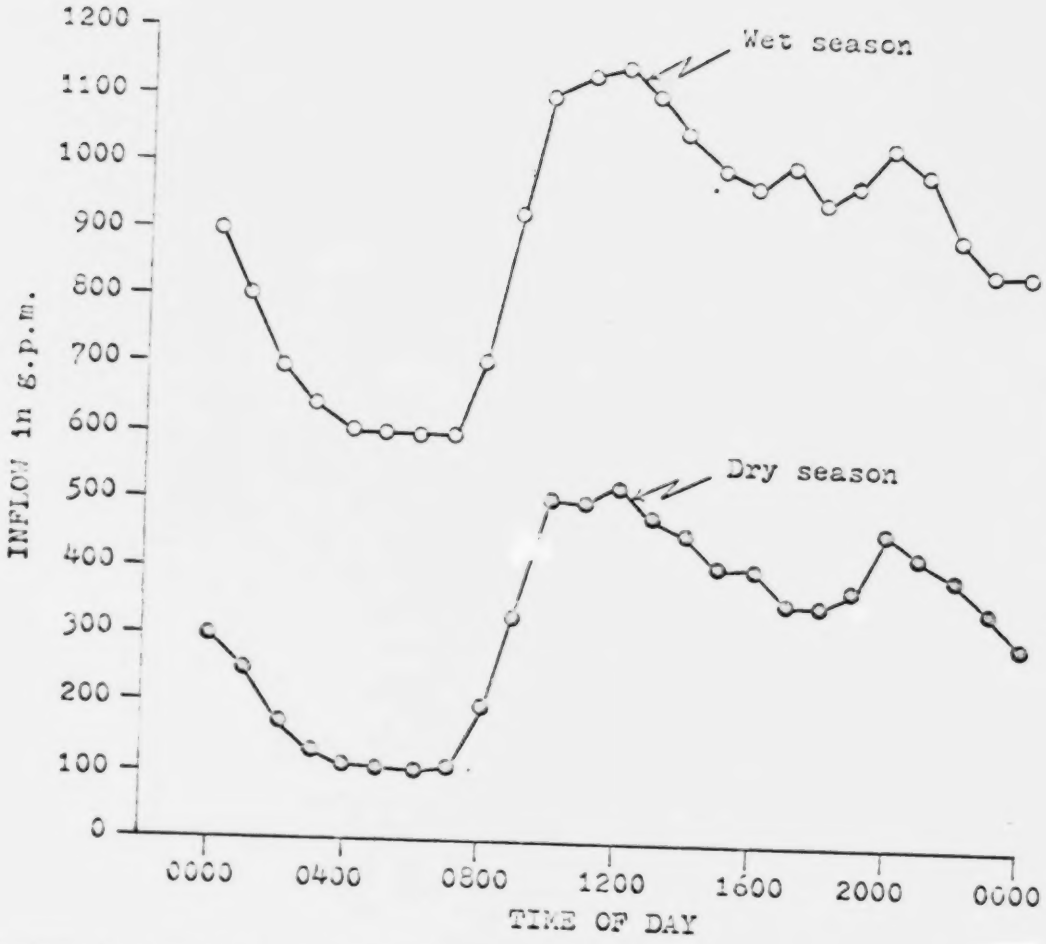



Figure 4.--Typical diurnal pattern of flow to the sewage oxidation pond during the "wet" and "dry" seasons, Arcata, California.

The effect of ground water infiltration on the volume of influent is clearly demonstrated (Figure 6 and Appendix B). In most cases, increases and decreases in monthly precipitation were accompanied by increases and decreases in the flow to the treatment plant.

The flows during July, August and September are believed to be very largely of waste origin since precipitation is essentially non-existent then. The data suggest that the "true" waste water and waste inflow is between 0.34 and 0.65 m.g.d. Therefore, for purposes of this report flows in excess of 0.65 m.g.d. are attributed to ground water infiltration.

## Chemical Quality

A comprehensive analysis of the chemical quality of samples taken from the oxidation pond near the inflow pipe outlet was conducted on June 14, 1961 by the California Department of Water Resources (Table 2). The results probably represent combined impounded pond water as well as fresh effluent from the clarifier, but they are presented here in the absence of more specific information.

## Detention Period

Herein, detention period is defined as the theoretical length of time (in days) that a given mass of waste and waste water remain within the confines of the oxidation pond basin at the normal water level. Periods are calculated by

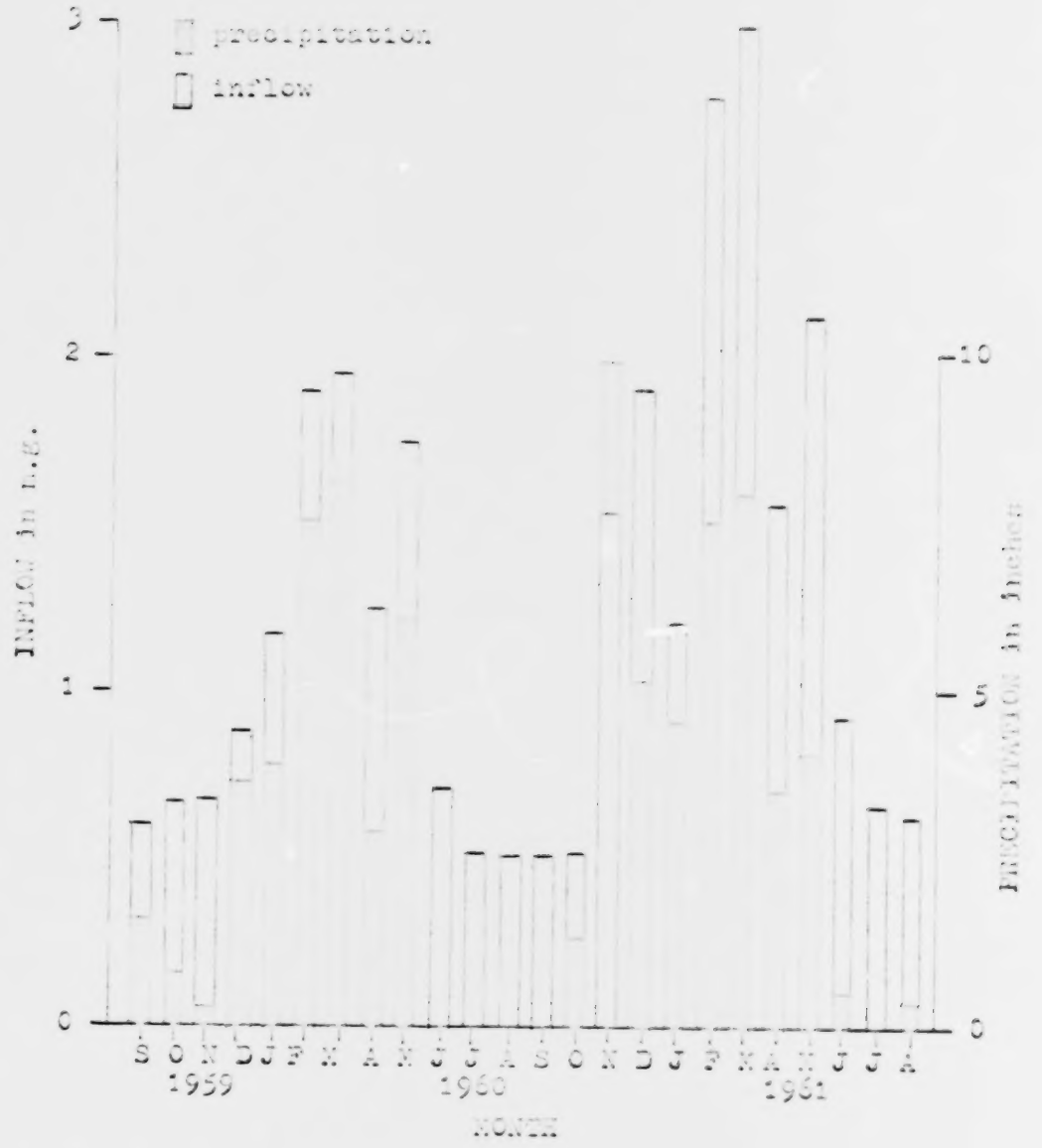



Figure 6.--Relationship between average metered daily inflow to the sewage oxidation pond at Arcata and monthly precipitation at Eureka, California.

Table 2.--Analysis of water sample taken on June 14, 1961, near the inlet pipe in the sewage oxidation pond, Arcata, California.1/

| Characteristic | Units |
|---|---|
| Silica | 24.00 mg/l |
| Calcium | 20.00 mg/l |
| Magnesium | 21.00 mg/l |
| Sodium | 119.00 mg/l |
| Potassium | 10.00 mg/l |
| Sulfate | 31.00 mg/l |
| Chloride | 104.00 mg/l |
| Fluoride | .02 mg/l |
| Boron | .02 mg/l |
| Ammonium | 6.40 mg/l |
| Nitrate | 0.20 mg/l |
| Ortho-Phosphate | 15.00 mg/l |
| Alkalinity, bicarbonate | 184.00 mg/l (as $CaCO_3$) |
| Hardness | 139.00 mg/l (as $CaCO_3$) |
| Specific Conductance | 916 micros @ 25°C. |
| pH | 7.5 |
| Suspended Solids | 10.00 mg/l |
| MBS | 3.10 mg/l |
| 5-day B.O.D. | 33.00 mg/l |

1/ Collection and analysis conducted by State of California Department of Water Resources, Division of Resources Planning, Surveillance Unit.

dividing monthly mean daily inflows into the operating volume of the pond (Table 7).

Detention periods range from 30 to 164 days (Appendix B). The detention time is, of course, inversely related to the inflow volume at any constant pond level (Figure 7). Detention periods are short during the wet season when flows to the pond are high. Conversely, detention periods are long during the dry season when flows to the pond are low.

During the summer months there are periods of no outflow from the pond. At these times the combined evaporation and seepage rates are roughly equivalent to pond inflow rates.

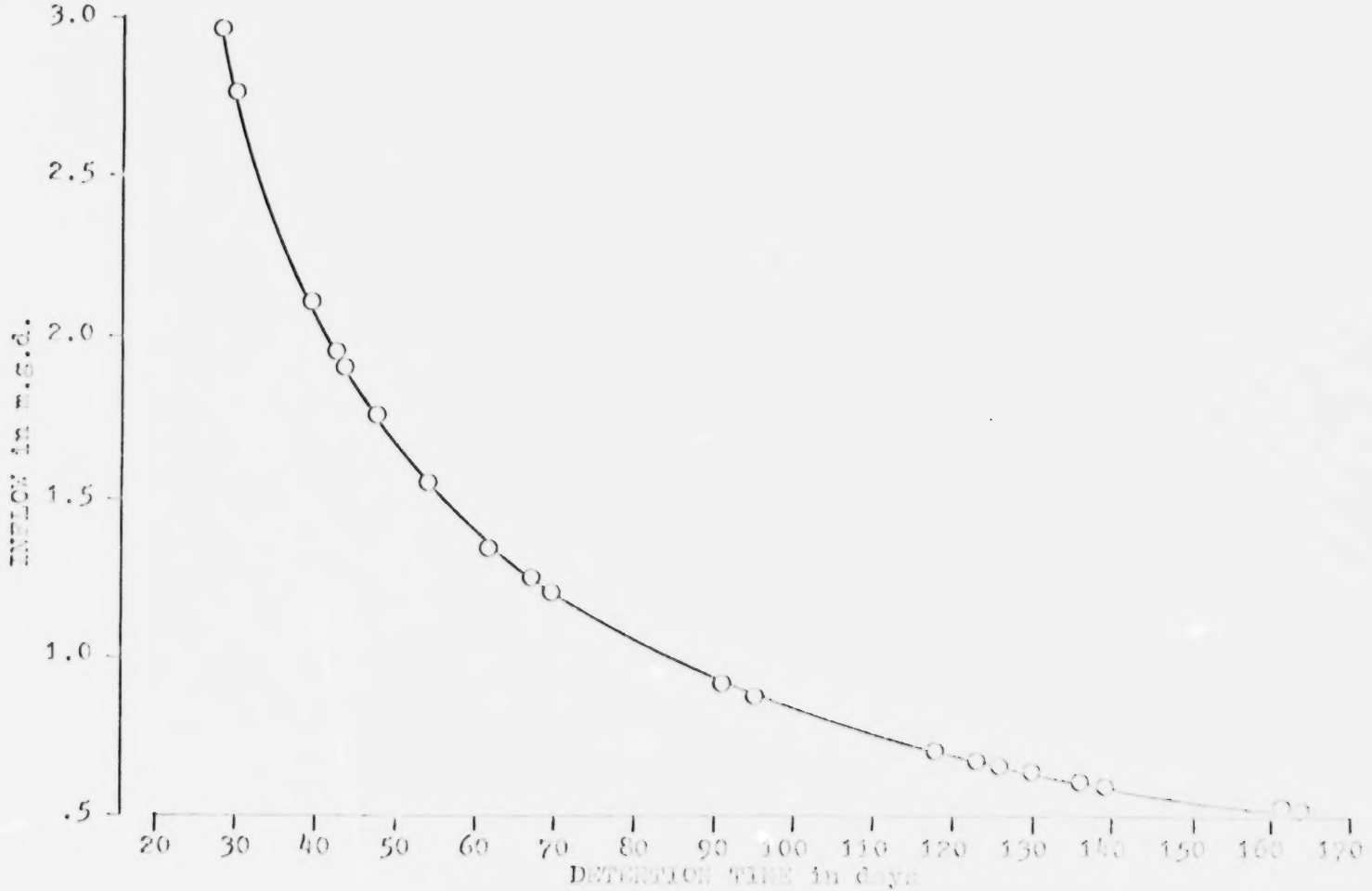



Figure 7.—Relationship between inflow and detention of impounded water in the sewage oxidation pond, Arcata, California.

## IV. FIELD AND LABORATORY METHODS AND PROCEDURES

### General

Data on temperature, dissolved oxygen, conductivity, pH, and transparency were gathered from the beginning of the study. Later, determinations of alkalinity, biochemical oxygen demand and nitrogen were included in the program. The sampling of pond water for physical and chemical analyses for the most part was conducted on a twice-a-week basis. Unless otherwise stated the analyses were conducted in accordance with the procedures outlined by the American Public Health Association, et al., in Standard Methods for the Examination of Water, Sewage and Industrial Wastes (1955) or Standard Methods for the Examination of Water and Wastewater (1960). The latter publication is an up-dated version of the former and was not available for use until midway in the study. Standard Methods (1955 or 1960) will be used from hereon to designate those publications.

### Establishment of Sampling and Observation Stations

Nine permanent stations were established (Figure 3). The station sites were not randomly selected, but every pond section was believed represented. Stations D, J, I, and H were located in a generally direct path from the region of the inflow to the outfall. Stations A, B, C, F,

and G were located around the perimeter of the pond about 50 feet from the shore; and station I was located at the boat dock, 2 feet offshore. With the exception of H and I, each station was marked with a 2-inch iron pipe driven into the mud. Stations H and I were near permanent structures and therefore required no special markings.

## Equipment and Procedures for Physical and Chemical Determinations

### Temperature

A continuous recording thermograph (Taylor, Model 963) was installed at station H on May 9th, 1960. The water temperature bulb was placed approximately 15 centimeters below the lip of the outlet board which maintains the operating water level of the pond. Temperatures at this depth herein are considered surface temperatures. The recording instrument was housed in a wooden cabinet which was protected from excessive heating by a white plywood shield. Both air and water temperatures were recorded in degrees Fahrenheit (°F.) on charts covering seven day periods. The readings were checked weekly against a reference thermometer and whenever discrepancies developed, notations and corrections were made.

Additional air and water temperatures were taken with a field hand thermometer. Air temperatures usually were recorded only at the first station reached each sampling day, whereas, water temperatures normally were recorded at every station. Fahrenheit values were later converted to Celsius (°C.) values.

Transparency

A Secchi disc, 20 centimeters in diameter, was used according to instructions in Whipple (1927) to obtain transparency readings. Depth readings were recorded in centimeters (cm). All observations were made by the same individual. There was no attempt to collect observations at the same hour or hours during each sampling period. Readings were taken irregularly, merely supplementing other observations.

Hydrogen Ion Concentration (pH)

Samples for determination of pH were collected from the surface of the pond and measured with a Beckman Model-G pH meter. During the dry season, determinations were made at the pond immediately after the samples were taken. During the wet season, the samples were placed in 300 ml biochemical oxygen demand (B.O.D.) bottles and taken to the laboratory for analysis.

Tests for determining precision of the technique used in pH analysis were conducted on Arcata pond water during the period July 11, and July 14, 1961 (Table 3). The standard deviation was calculated to range from 0.01 to 0.02. Standard Methods (1955) states that the standard deviation of the pH value of sewage using a glass electrode is 0.03 which agrees closely with the experimental results. This suggests that the method used is acceptable.

Specific Electrical Conductance (Conductivity)

Conductivity observations were taken early in the study but were discontinued when the equipment became inoperative.

Table 3.--Precision of techniques for the determination of pH of water samples collected from the sewage oxidation ponds, Arcata, California.

| Test Date | Number of observations | Mean pH | pH Range | Standard Deviation |
|---|---|---|---|---|
| 7-11-61 | 7 | 9.05 | 9.02-9.09 | .02 |
| 7-24-61 | 7 | 9.13 | 9.10-9.13 | .01 |
| 7-31-61 | 7 | 8.43 | 8.44-8.45 | .01 |

Samples were collected in 300 ml B.O.D. bottles and taken to the laboratory for analysis. Readings were taken with a Wheatstone bridge and conductivity cell. Observations were recorded in micromhos per centimeter (umhos/cm).

Dissolved Oxygen

Some water samples for dissolved oxygen analysis were collected in a 1200 cc Kemmerer water sampler equipped with a rubber delivery hose. Samples were taken by lowering the instrument to approximately 15 centimeters below the surface before tripping it. Since the Kemmerer sampler retains a vertical column of water 70 centimeters in length, the samples are therefore actually representative of a composite depth of 15 to 85 centimeters. For the purpose of this report, these are called "Kemmerer depth" samples. When samples from precise depths were desired they were taken with a sampler designed by Hazel (1963) and the exact depth recorded. All aliquots for dissolved oxygen analysis were placed in 300 ml B.O.D. bottles, chemically "fixed" at the pond by adding 2 ml each of manganous sulfate, alkaline-iodide solution and concentrated sulfuric acid, and then transported the laboratory for analysis. Water samples usually were analyzed immediately after they reached the laboratory. Occasionally, it was necessary to store some samples for later analysis. In such cases they were held under dark refrigeration at 1.1°C. for periods not exceeding 12 hours. Before analysis the refrigerated samples were immersed in a hot water bath and brought quickly to room temperature.

Fixed aliquots of 100 ml were titrated with 0.0125 N sodium thiosulfate ($Na_2S_2O_3$) which was standardized with potassium dichromate according to the method described by Ellis, Westfall and Ellis (1946). This method was selected to permit additional titration in the event error was suspected in the first run. Precision and speed in the titrations were made possible by a simple technique. Aliquots were withdrawn from the B.O.D. bottles into a 100 ml automatic pipette attached to an aspirator. The liquid was drawn into the pipette at the turn of the three-way stopcock and then with a second turn transferred to a 250 ml Erlenmeyer flask. While the solution was being rotated with a magnetic stirrer, titrant was delivered from a 25 ml automatic buret graduated in 0.1 ml. The results were recorded to the nearest 0.1 ml.

At the beginning of the study the dissolved oxygen samples were fixed in accordance with the Alsterberg (azide) modification of the Winkler procedure. It was later learned, however, that this modification produces low values when used in samples containing more than 15 mg/l dissolved oxygen or having a high organic content. Under these conditions the Pomeroy-Kirschman-Alsterberg (P.K.A.) modification was cited as being the most suitable for the analysis (Standard Methods, 1955). As a result the azide modification was replaced by the P.K.A. modification on October 29, 1960. The results of determinations made with the two modifications using Arcata oxidation pond water were compared (Table 4).

Table 4.--Comparison of the Winkler and the Pomeroy-Birnie-Winkler modification of the Winkler method for the determination of dissolved oxygen.

| Date | Time | Station | Winkler D.O. (mg/l) | P.B.W. D.O. (mg/l) | Difference mg/l | Difference % |
|---|---|---|---|---|---|---|
| 10-29-60 | 1100 | A | 11.1 | 14.0 | +2.9 | 26.1 |
| | | C | 10.3 | 12.8 | +2.5 | 24.3 |
| | | D | 12.8 | 15.7 | +2.9 | 22.7 |
| | | E | 12.2 | 14.3 | +2.1 | 17.2 |
| | 1530 | A | 10.6 | 13.5 | +2.9 | 27.4 |
| | | C | 10.3 | 12.7 | +2.4 | 23.3 |
| | | D | 10.3 | 12.4 | +2.1 | 20.4 |
| | | E | 10.3 | 12.7 | +2.4 | 23.3 |
| 11-4-60 | 0700 | A | 10.7 | 13.1 | +2.4 | 22.4 |
| | | C | 9.5 | 11.5 | +2.0 | 21.0 |
| | | D | 8.8 | 9.7 | +0.9 | 10.2 |
| | | E | 8.9 | 9.3 | +0.4 | 4.5 |
| | 1400 | A | 11.3 | 13.1 | +1.8 | 15.9 |
| | | C | 10.2 | 12.4 | +2.2 | 21.6 |
| | | D | 11.8 | 13.6 | +1.8 | 15.3 |
| | | E | 14.2 | 15.7 | +1.5 | 10.6 |
| 11-11-60 | 1400 | A | 10.2 | 11.0 | +0.8 | 7.8 |
| | | C | 10.0 | 11.2 | +1.2 | 12.0 |
| | | D | 10.7 | 12.5 | +1.8 | 16.8 |
| | | E | 10.0 | 12.4 | +2.4 | 24.0 |
| | 1700 | A | 10.9 | 11.1 | +0.2 | 1.8 |
| | | C | 10.4 | 12.4 | +2.0 | 19.2 |
| | | D | 11.8 | 13.7 | +1.9 | 16.1 |
| | | E | 10.9 | 13.6 | +2.7 | 24.8 |
| 11-12-60 | 0800 | A | 7.0 | 8.5 | +1.5 | 21.4 |
| | | C | 6.5 | 8.2 | +1.7 | 26.2 |
| | | D | 7.4 | 8.5 | +1.1 | 14.9 |
| | | E | 9.8 | 10.6 | +0.8 | 8.2 |

Each pair of aliquots for the determinations were taken from the same water sample. All but six of the dissolved oxygen concentrations determined by the Alsterberg modification were lower than those obtained by the P.H.A. modification. The differences between the results obtained by the two methods became greater with increased dissolved oxygen concentrations and saturations. Therefore, the oxygen values based on the Alsterberg modification are considered minimum.

Tests for determining the precision of the technique used for the determination of dissolved oxygen were conducted on Winkle oxidation pure water, using the P.H.A. modification of the Winkler method and 0.025 N sodium thiosulfate. Observations were repeated to the nearest 0.01 ml of sodium thiosulfate (Table 5). The standard deviation ranged from 0.03 ml to 0.07 ml. According to Standard Methods (1955) the dissolved oxygen in secondary effluents can be determined with a precision expressed as a standard deviation of 0.058 ml of 0.025 N sodium thiosulfate. The standard deviation may not exceed 0.1 ml in waters having organic suspended solids. Thus, the experimental data agree closely with reported standards and indicate that the technique used was satisfactory.

Per cent saturation of dissolved oxygen was computed according to the method described by Whipple and Whipple (1911). The data were recorded to the nearest 0.1 per cent.

Alkalinity

Samples for the analysis of alkalinity were extracted from the Kemmerer sampler after the samples for dissolved oxygen had been taken. The samples were placed in 300 ml B.O.D. bottles and transported to the laboratory for analysis.

Aliquots for alkalinity analysis were withdrawn in the same manner as that described previously for dissolved oxygen. Initially, alkalinity determinations were performed by titrating a 100 ml aliquot of a sample with 0.02 N sulfuric acid to the phenolphthalein and methyl orange end points as determined by eye. After November, 1960, all determinations were made with a Beckman model G pH meter. It was desirable to change methods because many water samples were colored or turbid, causing greater difficulty in determining visual end points. Meter values of 8.0 and 4.0 were used to correspond to the phenolphthalein and methyl orange end points respectively. The alkalinity values were recorded to the nearest 0.1 mg/l.

Tests for determining the precision of the technique used for alkalinity analyses were conducted on Austin sewage oxidation pond water. The observations were recorded to the nearest 0.01 ml (Table 6). Although the standard deviation ranged from 0.02 ml to 0.14 ml, these results can not be compared with Standard Methods (1955) or 1960) since precision standards for the potentiometric method were not available at this writing.

Table 5.--Precision of techniques for the determination of dissolved oxygen of water samples collected from the sewage oxidation ponds, Arcata, California.1/

| Test Date | Number of observations | Mean (mg) | Range (mg) | Standard Deviation (mg) |
|---|---|---|---|---|
| 7-21-61 | 7 | 2.98 | 2.7 - 3.2 | .21 |
| 7-25-61 | 7 | 3.28 | 3.1 - 3.5 | .08 |
| 7-26-61 | 7 | 11.14 | 10.9 - 11.3 | .09 |
| 7-31-61 | 7 | 10.57 | 10.30 - 10.84 | .09 |

1/ Mean and range values are presented in terms of mg. of $O_2$ per liter of sample. Titrimetric determination of dissolved oxygen. Sample values were not corrected to dissolved oxygen concentrations.

Table 6.--Precision of techniques for the determination of phosphorus in the total alkalinity of water samples collected from the sewage oxidation pond, Arcata, California.1/

| Date | Phosphate, dissolved | | | | Total dissolved | | | |
|---|---|---|---|---|---|---|---|---|
| 1961 | No. obs. | Mean | Range | Std. dev. | No. obs. | Mean | Range | Std. dev. |
| 7-11 | 5 | 1.97 | 1.96-1.97 | .00 | 6 | 19.38 | 17.47-21.34 | .09 |
| 7-18 | 7 | 3.03 | 2.97-3.11 | .05 | 7 | 18.85 | 17.71-21.28 | .17 |
| 7-24 | 6 | .00 | .00-.01 | .00 | 7 | 19.05 | 18.80-19.92 | .10 |

1/ Values are in terms of ml of 0.02 N $H_2SO_4$ required to titrate sample to pH 8.0 and 4.5.

Methods

The nitrogen analyses were performed both in the study by Mr. John Cooper, a senior chemistry student at Humboldt State College. Although more than three of the stated three areas are included in this thesis as a means of placing under one cover all of the available physical and chemical information concerning the Arcata sewage oxidation pond.

Samples for nitrogen analysis were collected by immersing about 300 ml B.O.D. bottles just below the surface at station A. Immediately upon collection the bottles were placed in an ice bath and taken to the laboratory for analysis. The procedures used for ammonia, nitrate, nitrite, and organic nitrogen determinations were modifications of the basic methods outlined in Standard Methods (1960). The selected procedures and modifications employed are described below.

Ammonia nitrogen-aeration distillation method was used for the determination of ammonia. Within one hour after being removed from the ice bath, each sample was divided into three 100 ml aliquots and distilled separately. Following distillation the samples were placed in stoppered 250 ml Erlenmeyer flasks and stored until analysis. Three runs were made on each distillate using 25 ml aliquots. Absorbance readings were taken with a Beckman model B-400 D.U. spectrophotometer at a wave length of 40 mu and a slit width of 0.025 mm. Average absorbance readings were compared to a standard curve that was prepared by plotting absorbancy of

solutions of known ammonia concentrations against their concentration. The observations were recorded to the nearest 0.01 mg/l.

Error in analysis was determined using four solutions of known ammonia concentration. The absorbance of each solution was measured twice and the average reading was used to determine the concentration of known samples. A two per cent error was observed (Table 7). Possible sources of error include:

1. Preparation of standard (weighing and diluting),
2. Transfer of standard,
3. Distillation,
4. Dilution of distillation,

and 5. Absorption reading.

Interfering substances can also affect the determination. Standard Methods (1960) states that turbidities and/or off color will develop when interfering substances are present. Hence, if any interference is suspected, however, since no turbidity or off color developed during the neutralization step.

Tests of precision were conducted simultaneously with the accuracy tests (Table 7). The standard deviation was calculated as 0.22 mg/l. Standard Methods (1960) states that precision of the method expressed as standard deviation is 0.15 mg/l which agrees closely with the experimental results. Thus, the data suggest that the procedure used is acceptable.

Table 7.--Accuracy and precision of the distillation method for the determination of ammonia nitrogen

| Sample | Volume (ml) | Absorbance | | | Ammonia concentration (mg/L) |
|---|---|---|---|---|---|
| | | Run 1 | Run 2 | Mean | |
| 1 | 250 | .170 | .170 | .170 | 9.6 |
| 2 | 250 | .171 | .170 | .170 | 9.6 |
| 3 | 250 | .171 | .170 | .170 | 9.6 |
| 4 | 250 | .169 | .169 | .169 | 9.6 |

Mean = 9.6 mg/L
Standard deviation = 1.22 mg/L.
Coefficient of variation = 2.0 %

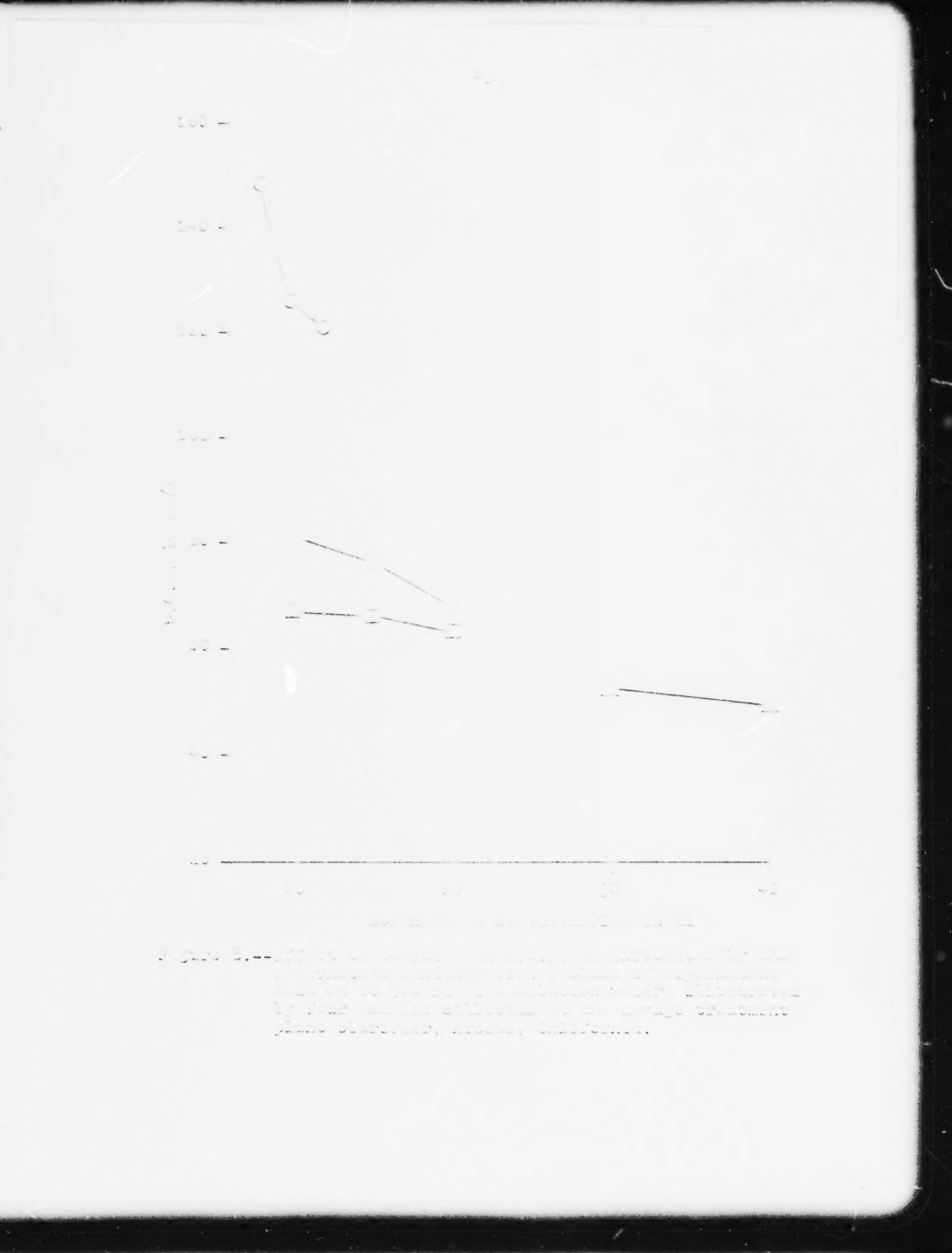
Table 3.--Precision of methods for the determination of organic nitrogen in water at the Ohio River Laboratory, Wheeling, West Virginia

| Sample | Volume digested (mL) | Organic nitrogen (mg/L as N) |
|---|---|---|
| 1 | [illegible] | [illegible] |
| 2 | [illegible] | [illegible] |
| 3 | [illegible] | [illegible] |

Mean = [illegible] mg/L organic nitrogen
Standard deviation = [illegible] mg/L organic nitrogen

Table 1.--Calculation of the Gaussian curve for the estimation of missing records.

| Class limits (cfs) | Number | Class mean (cfs) | Deviation from mean (cfs) | Deviation squared (cfs) |
|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |



# V WATER QUALITY CHARACTERISTICS

## General

The results are presented to show relationships among several stations sampled during the same time interval, diurnal relationships at a single representative station, and seasonal relationships at a single representative station. The station most often used to demonstrate diurnal and seasonal relationships was station H. This station was selected primarily because it could be reached at all times by car whereas the other stations (except I) could only be reached by boat.

## Surface Water Temperatures

### Differences among Stations

The pond surface showed a moderate daily uniformity of temperature. Differences among stations never exceeded 2.7°C. and in most instances were less than 1°C. Temperatures at station H remained within 1.5°C. of those recorded at other stations during the same observation period.

### Representative Diurnal Patterns

Four examples were selected to show temperature patterns on a sunny summer day (August 5), a cloudy summer day (August 10), a sunny winter day (December 29) and a cloudy winter day (December 1) (Figure 9). The August 5th pattern

represents the maximum range in temperature (6.3°C.) observed on any one day. The December 29th pattern represents one of the days when the observed minimum temperature of 6.1°C. occurred. The December 1st and August 10th curves show complete uniformity of temperature throughout the entire day and clearly demonstrate the stabilizing effect of a cloud cover.

Representative Seasonal Changes

The seasonal surface temperature pattern of the Arauca oxidation pond is represented by thermograph data collected at station H during the period May 13, 1960, through July 31, 1961 (Figure 10). The overall annual fluctuation in surface temperature was 19.5°C. The highest temperature noted was 25.6°C. (on July 11, 1961). Lows of 6.1°C. were recorded on December 9, 10, 11, 12, and 29, 1960.

Summer conditions (June-August) were characterized by prevailing mean temperatures ranging from 17.2°C. to 22.0°C. Winter conditions (December-February) were characterized by prevailing mean temperatures ranging from 7.7°C. to 11.7°C.

The maximum, minimum and mean monthly temperatures at station H are summarized in Appendix C.

Transparency

General

A total of 151 Secchi disc observations were made on 47 different days from April, 1960 to July, 1961. Depth readings ranged from 17 cm to 120 cm. The minimum value

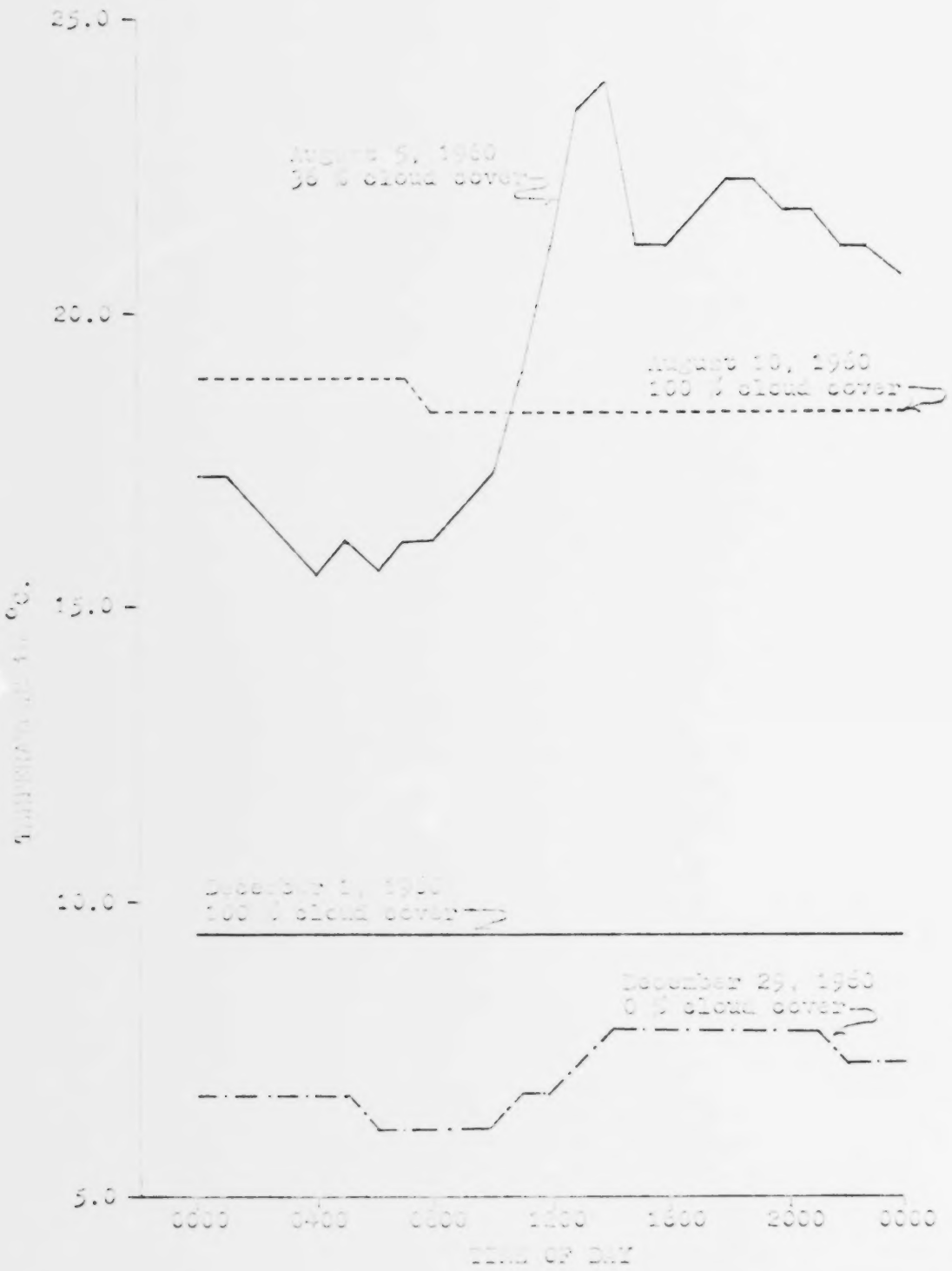



Figure 9.--Calibrated examples showing summer and winter diurnal temperature patterns at station M, in the sewage oxidation pond, Arcata, California.

Figure 10.—Surface water temperatures at selected U.S. Bureau of Reclamation reservoirs in California, Arizona, and Colorado.

was recorded at station 2 (on February 5, 1960) and the maximum also was recorded at station 4 (on April 22-23, 1961). The maximum monthly range was 30 cm (May, 1961) and the mean depth was 48.5 cm.

Monthly maximum and minimum observations are summarized in Appendix 2.

Differences under Station

Secchi disc value differences among stations ranged from 3 to 65 cm (Figure 11). The mean range of differences among stations was 19.3 cm. The readings at station 4 were found to differ from the other stations at any one time by as much as 10.3 cm.

Representative Diurnal Changes

During the study three diurnal series of observations were taken at station 2 (Figure 12). No consistent diurnal pattern is evident although the lowest Secchi disc readings were observed on a day when cloud cover prevailed.

Representative Seasonal Changes

Indications of possible seasonal changes in transparency were sought at station 4, but no regular pattern of change was evident (Figure 13). The overall range was 65 cm. The highest value was 110 cm (on May 13, 1961), and the lowest was 25 cm (on April 19, 1960). The mean value was 50.1 cm.

Figure 11.--Monthly maximum, minimum and mean differences in temperature (Secchi disc depth) among sampling stations in the average ostiottion pond, Azusa, California.

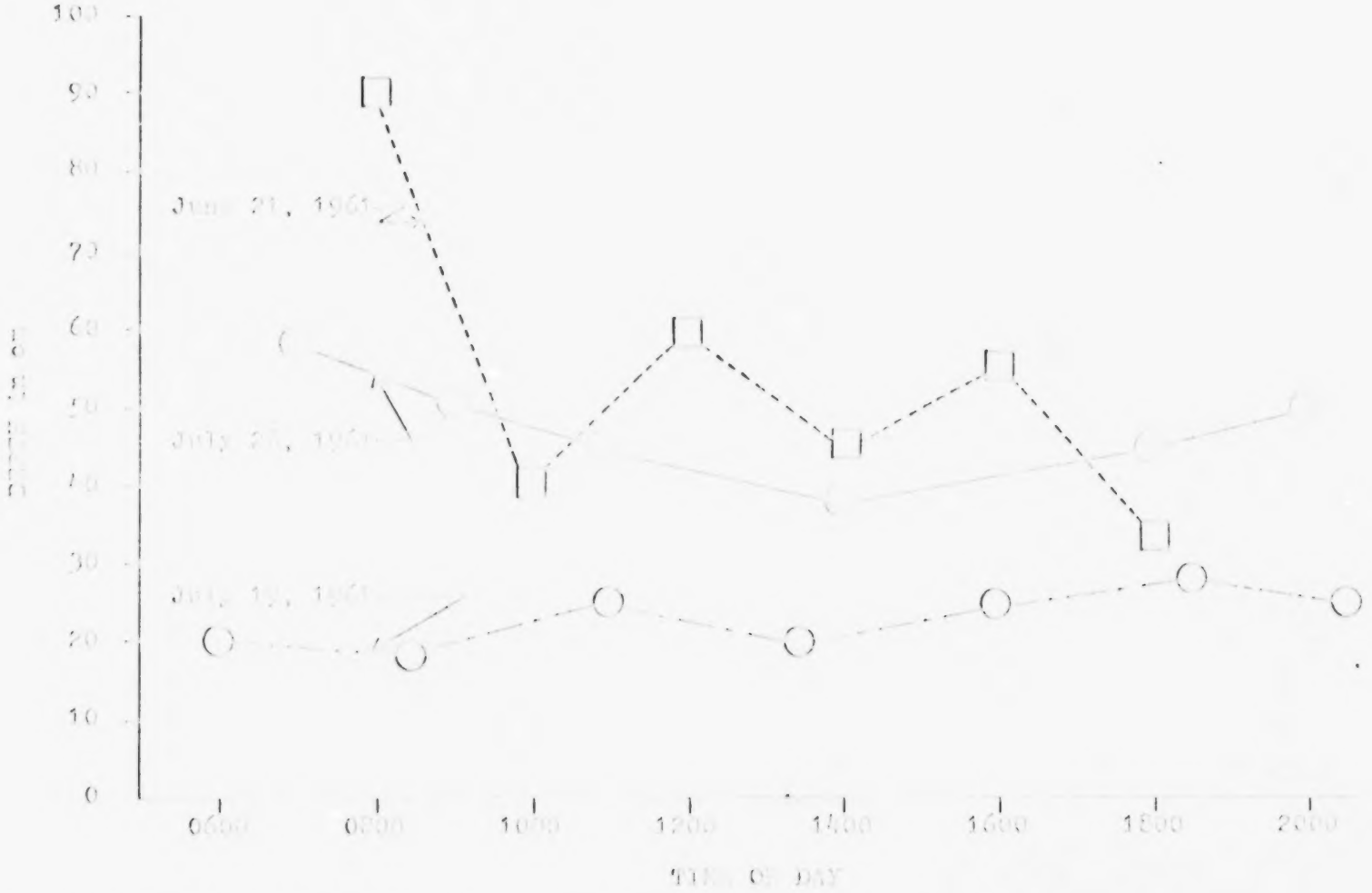



Figure 12.— Selected examples showing diurnal temperature (Secchi disc depth) patterns at station E in the sewage oxidation pond, Arcata, California.

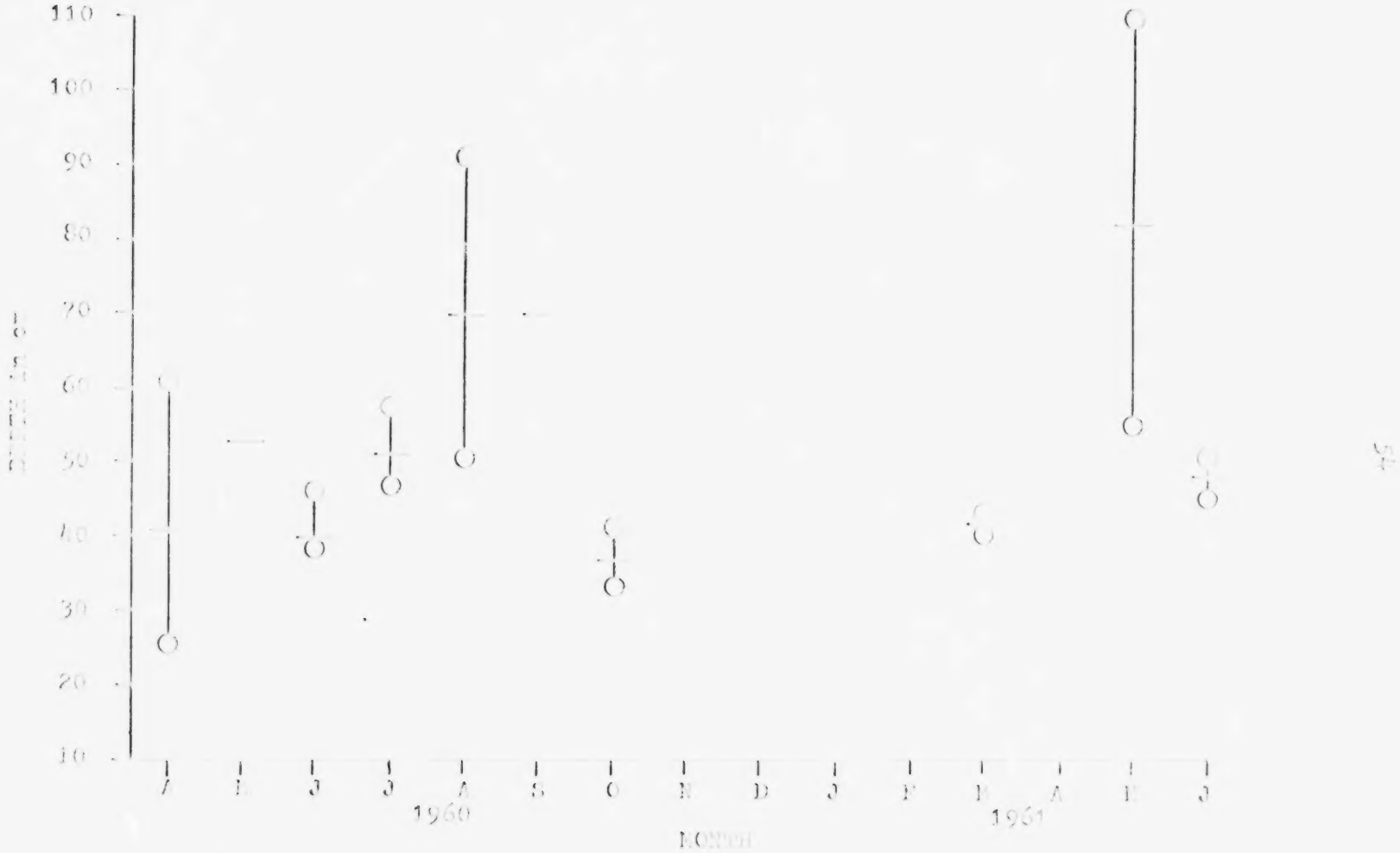



Figure 13.--Monthly maximum, minimum and mean transparency (Secchi disc depth) observations at station H in the sewage oxidation pond, Arcata, California.

## Hydrogen Ion Concentration

### General

During the period September, 1959, through August, 1961, 473 pH determinations were made. The values obtained ranged from 6.6 to 9.62. The minimum value was recorded at station I (on May 28, 1960), and maximum was recorded at station K (on July 12, 1961). The mean monthly range was 1.04 and the maximum range for any one month (June, 1960) was 2.15.

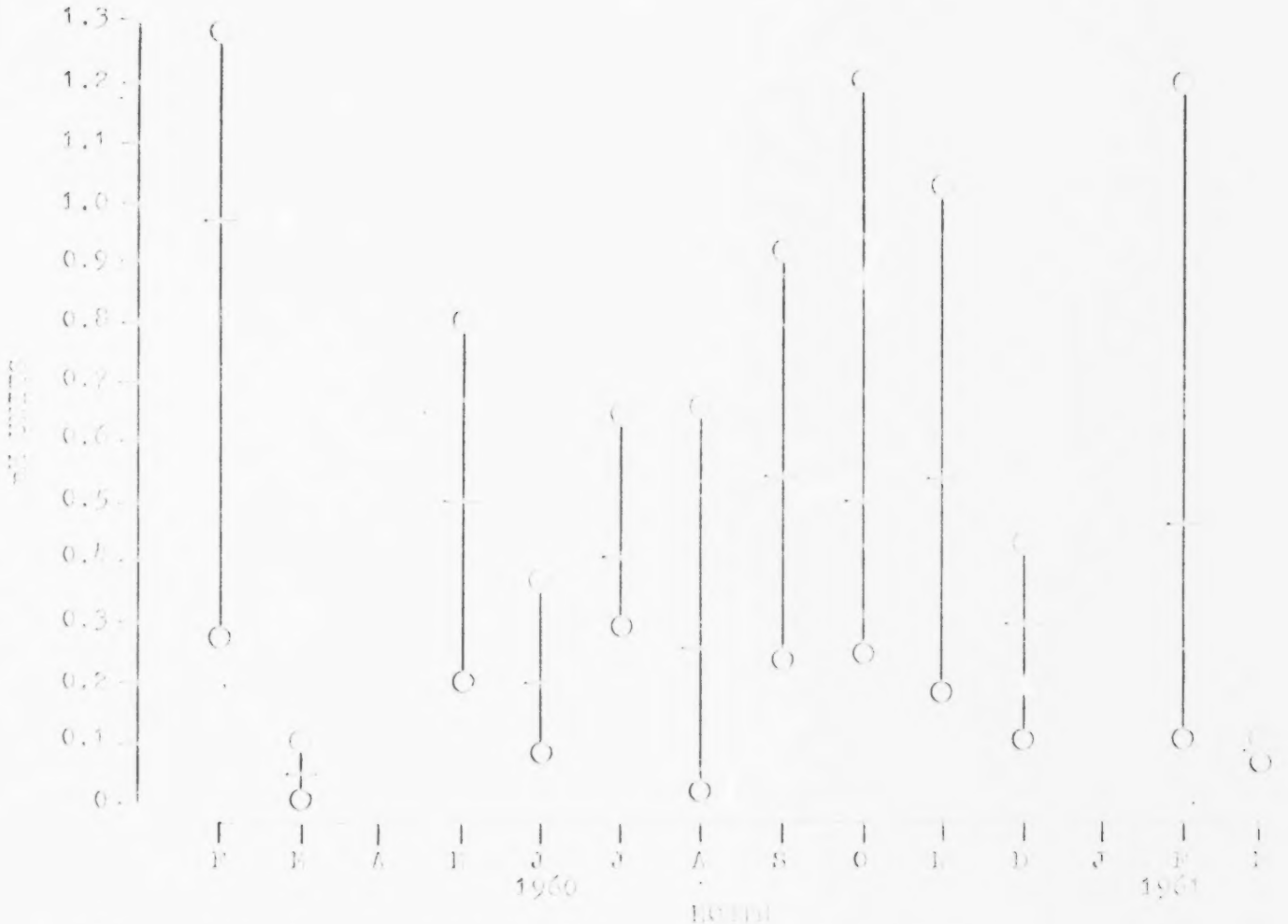
The monthly maximum, minimum and mean values of all observations are summarized in Appendix B.

### Differences Among Stations

Differences in pH among stations sampled within the same time interval were small (Figure 14). The maximum difference of 1.20 units occurred in February, 1960. There was no measurable difference among stations in March, 1961. The mean difference among all observations was 0.42 units. The pH at station K was found to differ from the other stations at any one time by no more than 1.20 units.

### Representative Diurnal Pattern

During the study fourteen diurnal series of observations were made at station K. The daily pH range never exceeded 1.29 units. The mean range was 0.49 units. The diurnal pattern which occurred on July 12-13, 1961, is typical (Figure 15). The pattern is one of increase during the daylight hours and decrease during the hours of darkness.


1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
F
M
A
M
J
J
A
S
O
N
D
J
F
M
1960
1961

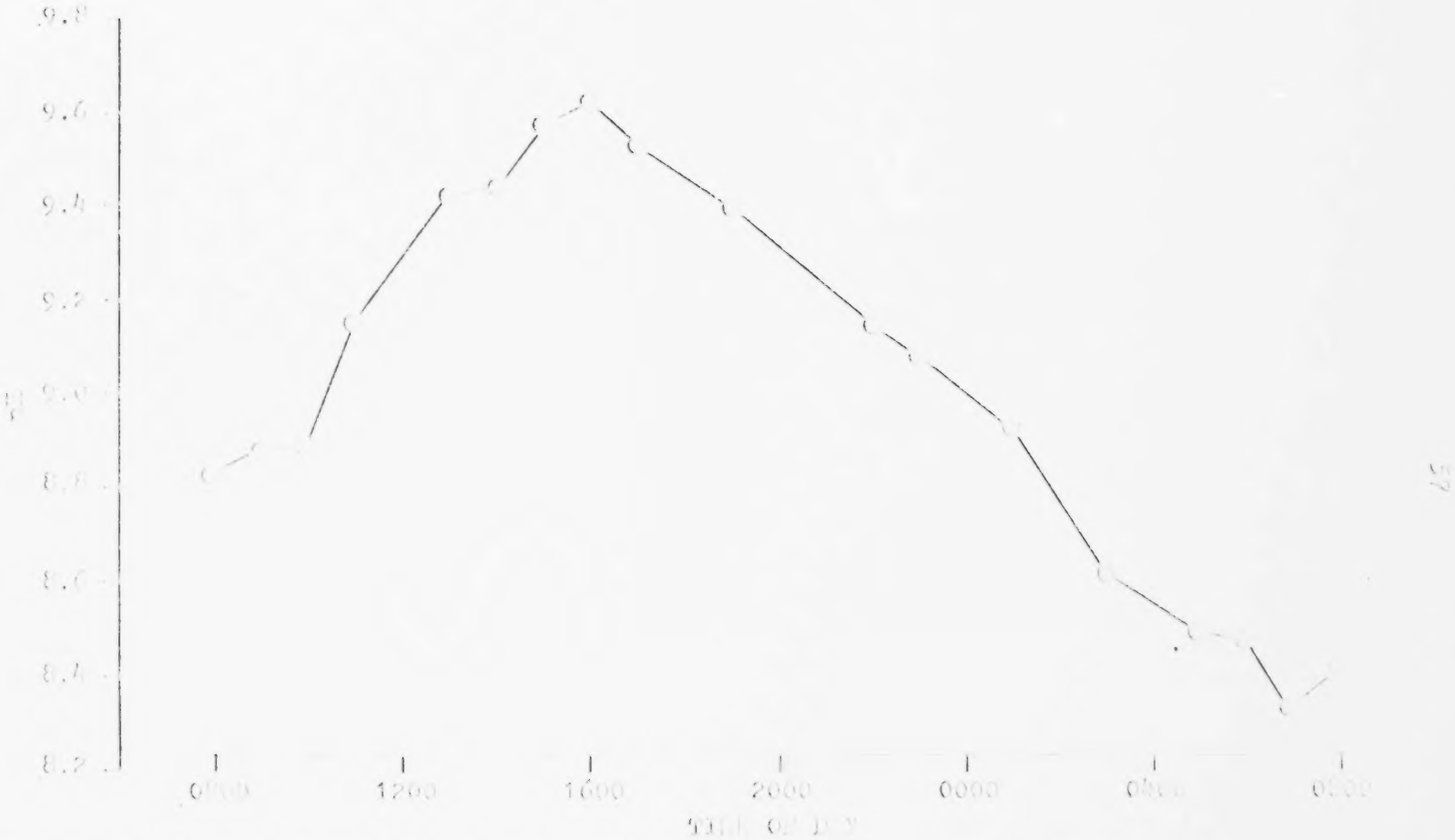



Figure 15.--Selected example showing diurnal pH pattern at station 1, in the sewage oxidation pond, Arctic, California.

[illegible]

The monthly minimum, maximum and mean pH values observed at station A [illegible] although the highest values occurred in the summer (Figure 16). The overall fluctuation was 1.4 units. The maximum pH noted was 9.02 (on July 12, 1961) and the minimum was 7.19 (on March 7, 1961).

## Specific Electrical Conductance

### Methods

Eighty-eight conductivity observations were made between July 24, 1959 and June 29, 1960. The values ranged from 750 to 4255 micromhos/cm. The minimum value was observed at station E (on March 27, 1960, and the maximum was observed at station A (on September 11, 1959). The maximum range for any one month was 1285 (August, 1959) and the least monthly range was 500 micromhos/cm.

The monthly minimum, maximum, and mean values of all observations are summarized in Appendix F.

### [illegible]

Conductivity distributions among stations ranged from 0 to 1035 micromhos/cm (Figure 17). The conductivity at station A was found to differ from the other stations at any one time by no less than 315 and not more than 750 micromhos/cm.

### [illegible]

During the study the maximum number of observations were made at station A. The data suggest that conductivity

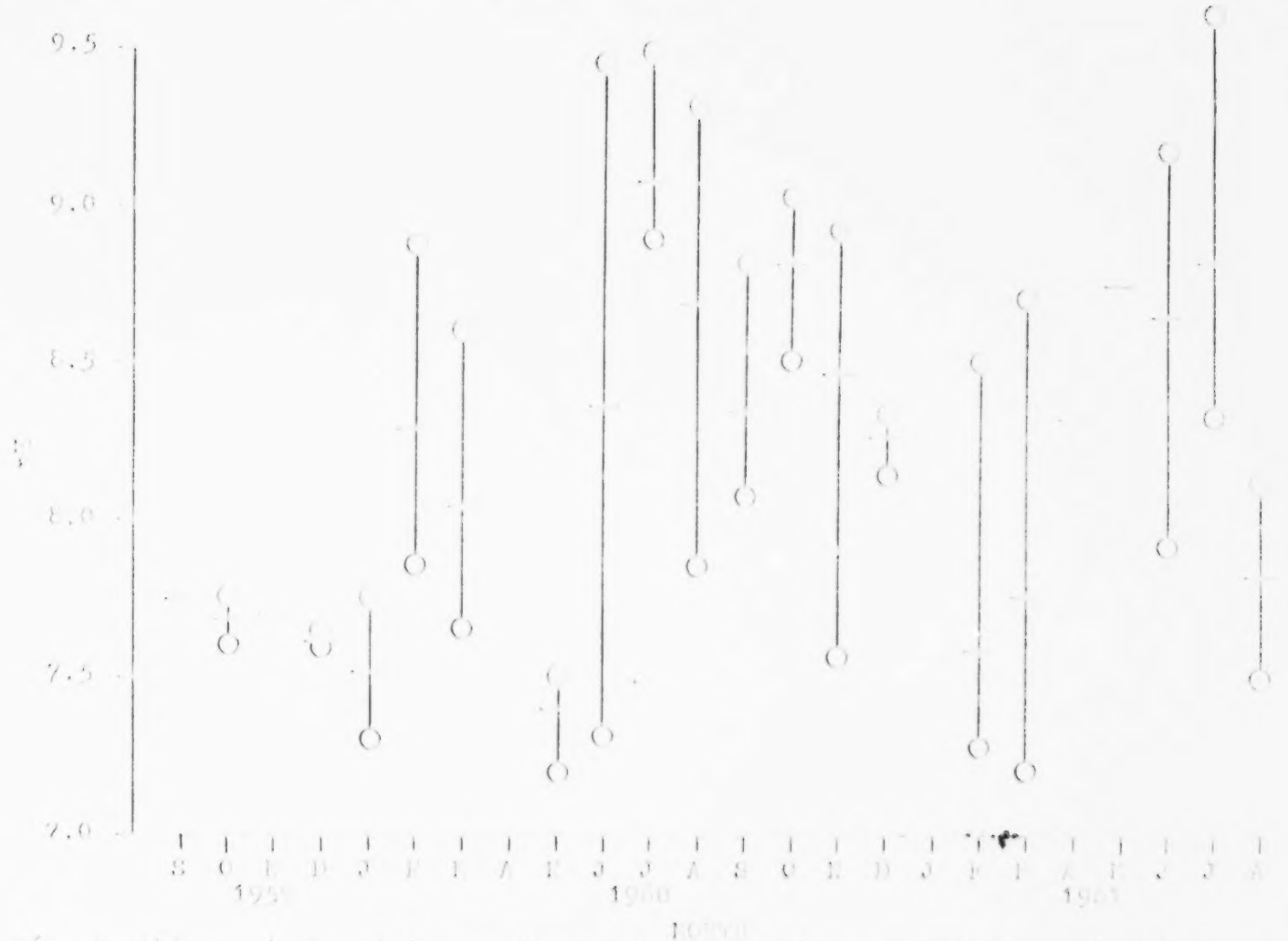



Fig. 16.- Monthly high, median and low pH of the surface at station B, in the kelp

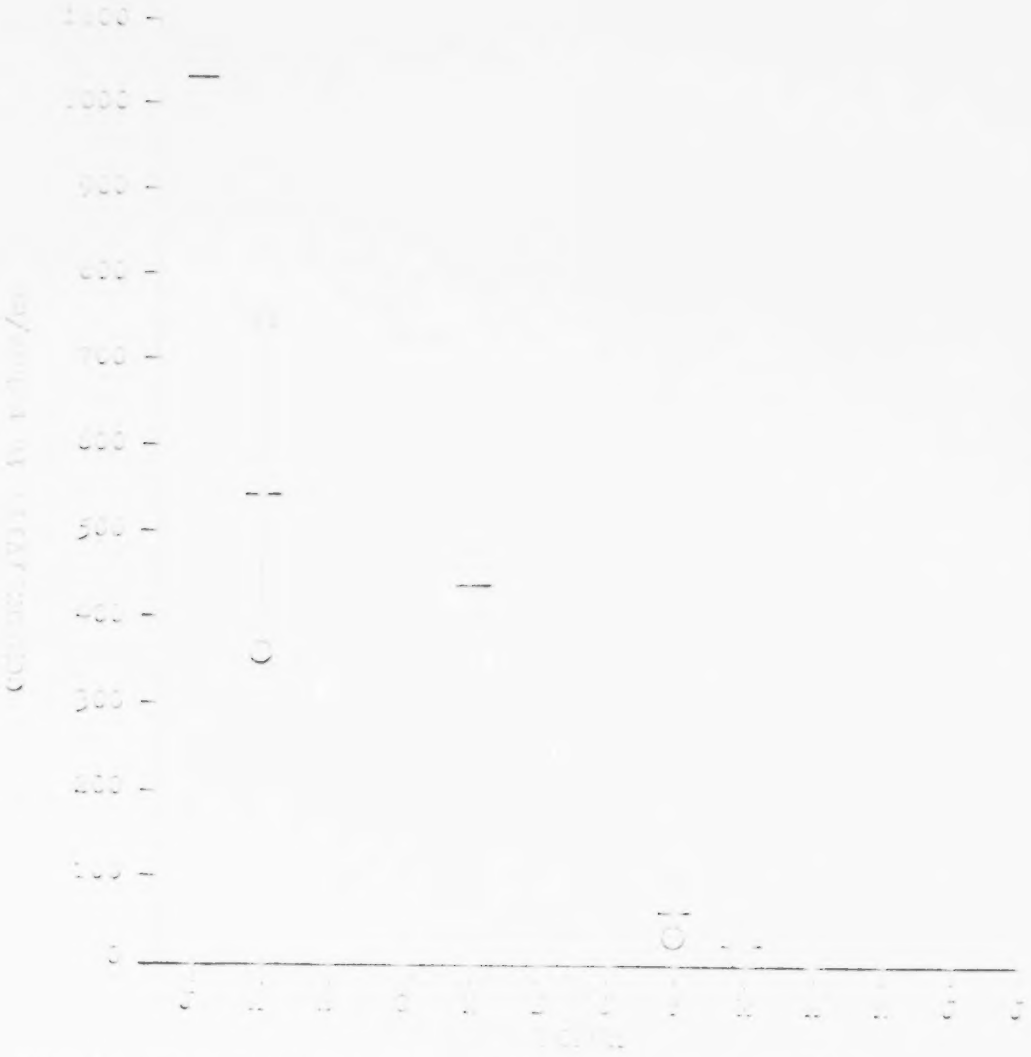
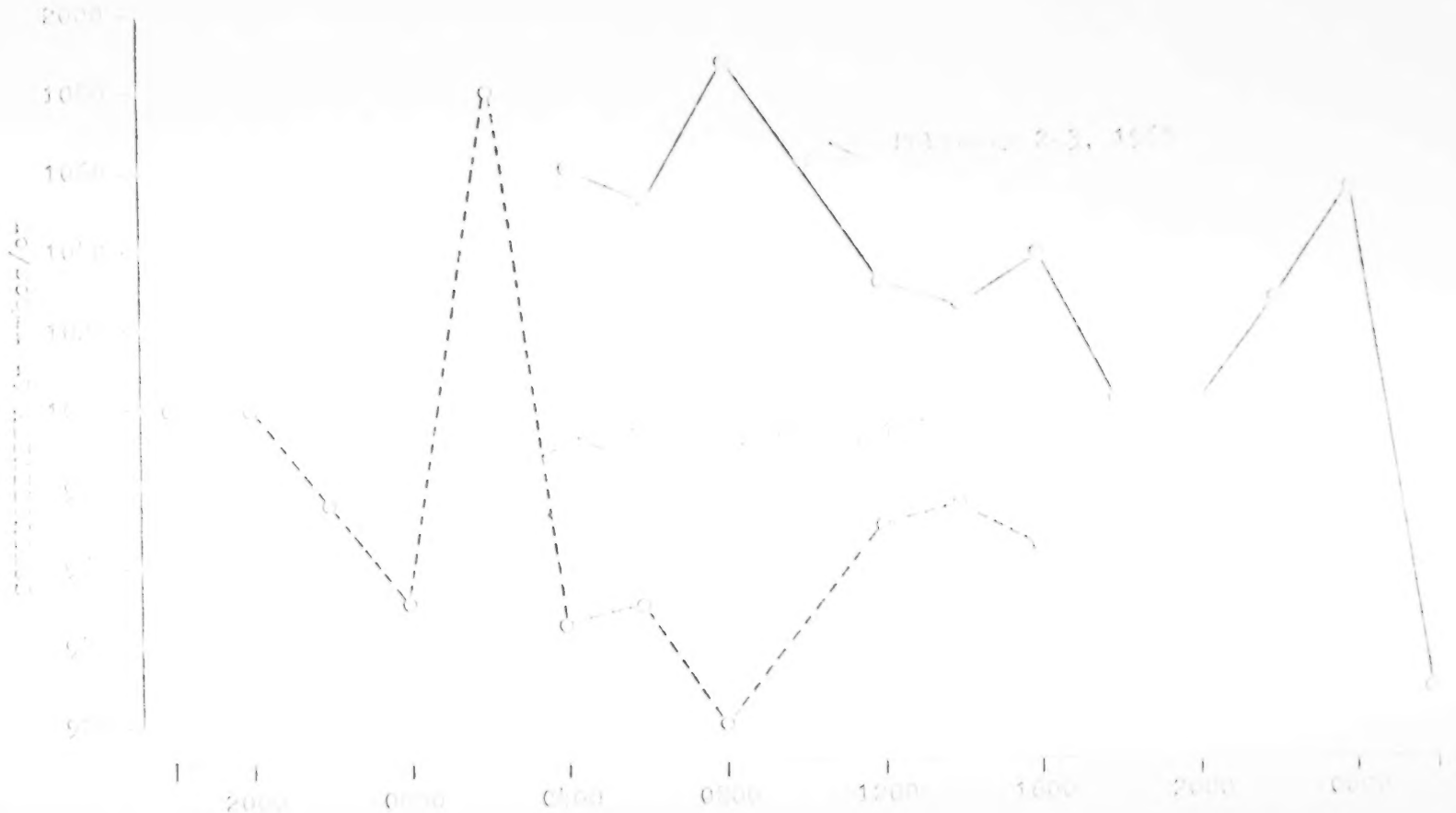


Figure 17.--Monthly maximum, average, and minimum temperatures at Collbran, Colo., Powell, Wyo., Gunnison, Colo., and Grand Junction, Colo., airports, 1931-60.

[illegible]

[illegible]

[illegible]



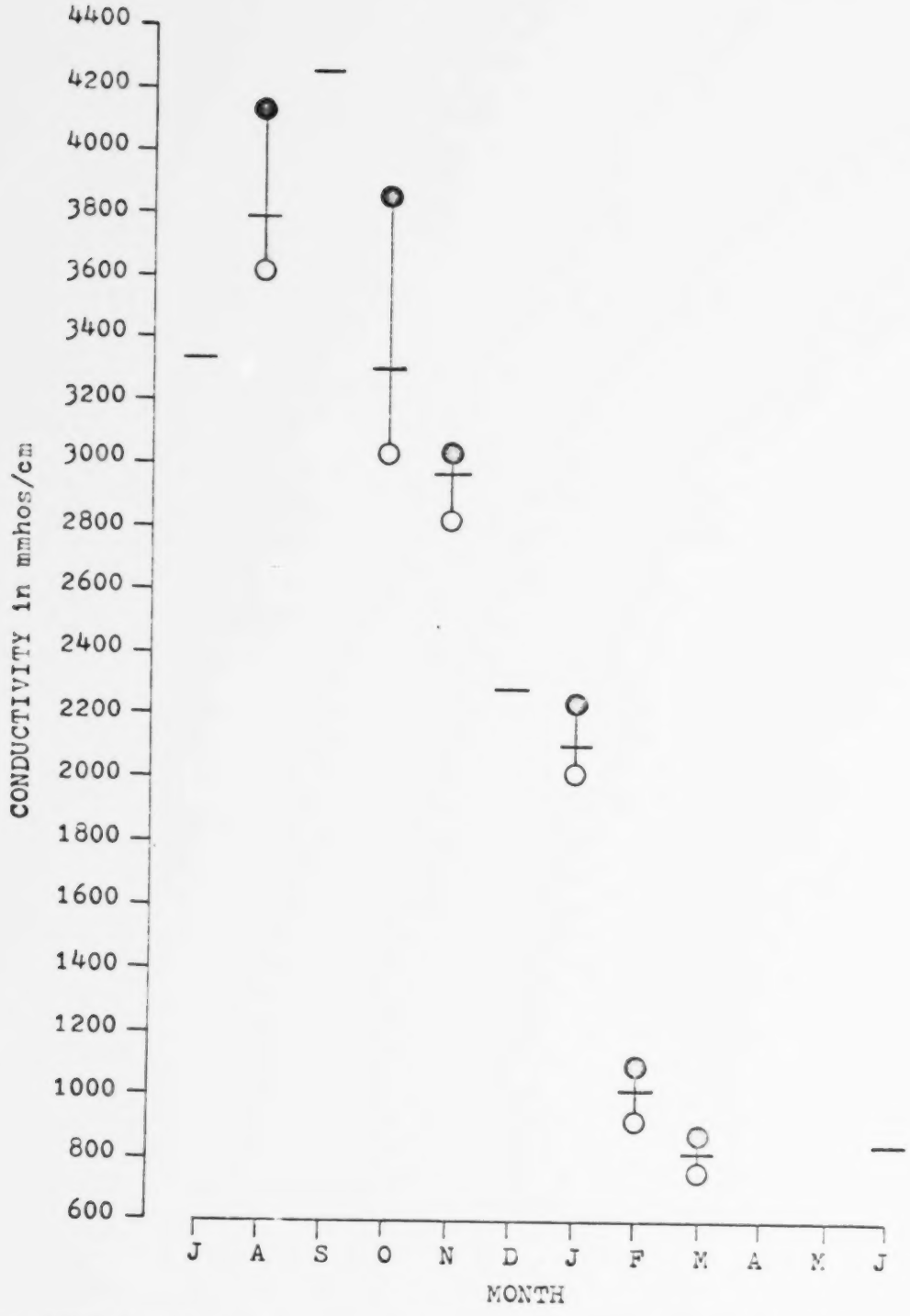



Figure 19.--Monthly maximum, minimum and mean conductivity observations at station H, in the sewage oxidation pond, Arcata, California.

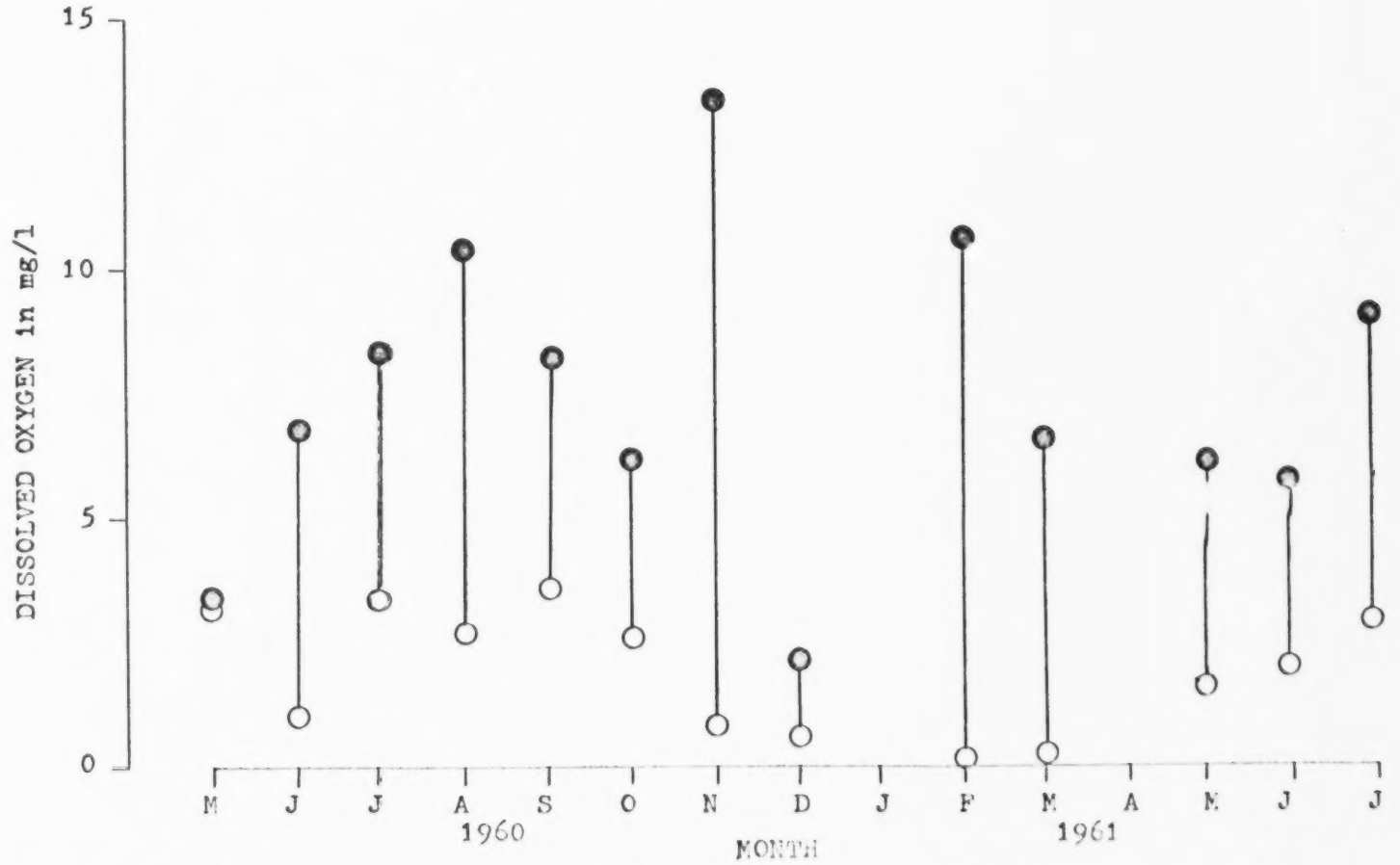



Figure 20.--Monthly maximum and minimum differences in Kemmerer depth dissolved oxygen among sampling stations in the sewage oxidation pond, Arcata, California.

maintained the highest or lowest concentration of a sampling series. Often a station exhibiting the maximum observation on one series would exhibit the minimum on the following series. Concentrations at station H were found to differ from those at the other stations at any one time by as much as 13.3 mg/l.

Representative Diurnal Pattern

During the study, 13 extensive diurnal series of Kemmerer depth dissolved oxygen observations were made at station H (Figure 21). The ranges observed were from 1.7 mg/l (on May 27-28, 1960) to 20.5 mg/l (on July 22-23, 1961).

Four series of diurnal observations were selected to represent typical dissolved oxygen relationships in the Arcata pond (Figure 22). It is clearly evident from the April 7-8, 1961, July 12-13, 1961 and November 26-27, 1960 curves that during the course of a day dissolved oxygen levels can vary considerably. The fluctuations tended to follow a daily pattern of midday highs and nocturnal lows. The hourly rate of increase in concentration was generally at a maximum in the morning and early afternoon (calculated to be as much as 4.4 mg/l per hour) and sharply reduced in the late afternoon and early evening. Loss of oxygen to the atmosphere (at supersaturation levels) and to the biochemical oxygen demand of organic matter resulted in lowering the concentration to less than saturation at night. Only during a long period of cloudy or foggy weather did this pattern change (May 27-28, 1960 curve). At such times no pronounced

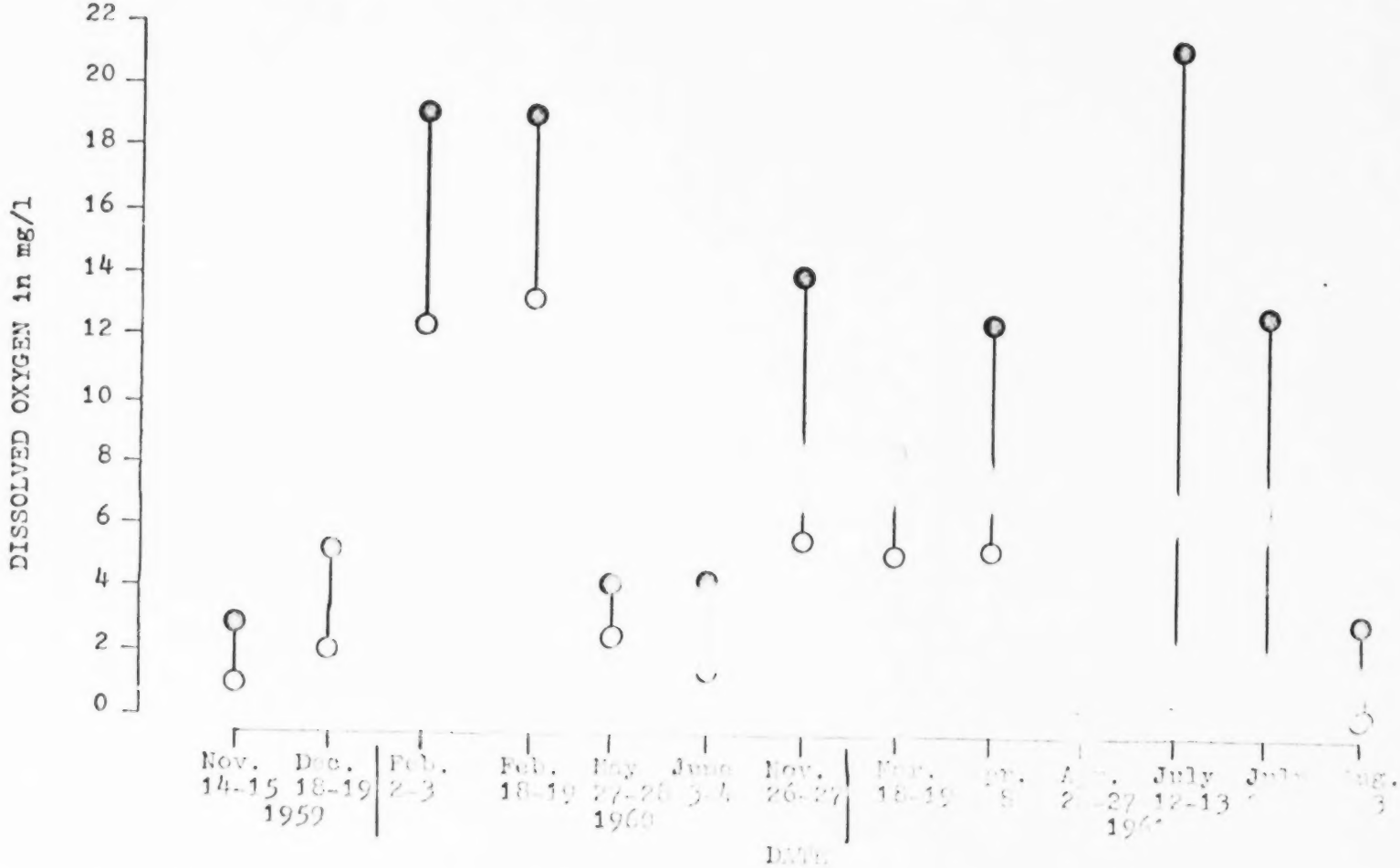



Figure 21.--Diurnal ranges of Kemmerer depth dissolved oxygen [illegible] at station H, in the sewage oxidation pond, Arcata, California.

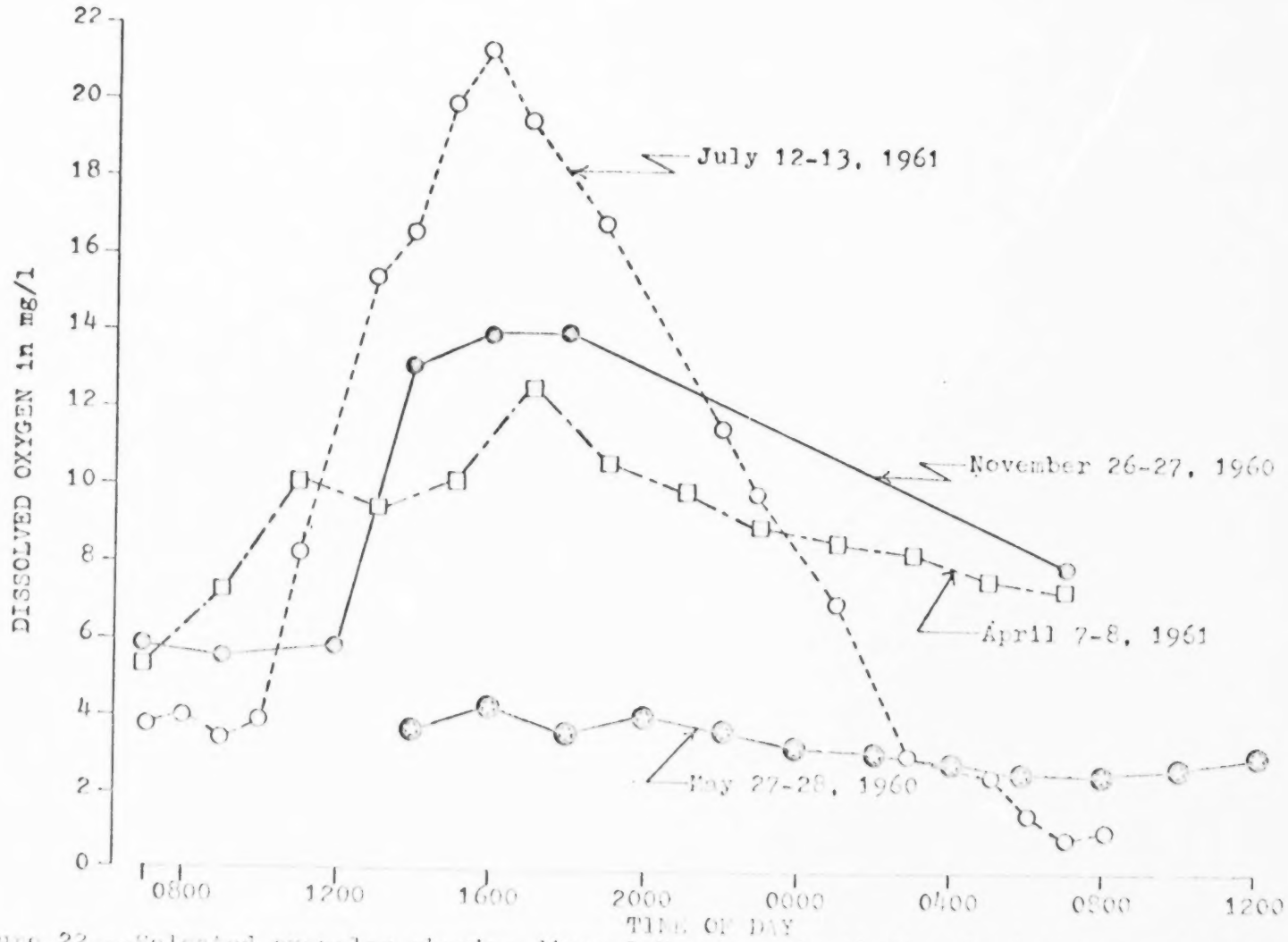



Figure 22.--Selected examples showing diurnal Kemmerer depth dissolved oxygen pattern at station H, in the sewage oxidation pond, Arcata, California.

diurnal pattern was evident and often dissolved oxygen was maintained at low or near zero levels.

A diurnal vertical distribution pattern was observed at station E on June 21, 1960 (Figure 23). Before 1000 hours, concentrations of dissolved oxygen at the four depths were almost identical; they did not vary from each other by more than 0.2 mg/l. At noon, concentrations on the bottom showed a slight decrease while the higher strata began to show marked increases in concentration. Afternoon (1400 hours) wind activity brought about a return to near uniformity as only a difference of 0.7 mg/l was observed from surface to bottom. By late afternoon (1800 hours), however, reduced wind activity allowed greater vertical differences to develop once again.

Representative Seasonal Changes

Monthly maximum and minimum observed Kemmerer depth dissolved oxygen concentrations at station H had an overall fluctuation during the study period of 23.0 mg/l (Figure 24). The highest concentration noted was 23.1 (on June 23, 1960). The recorded low was 0.1 mg/l (on August 3, 1961). The maximum monthly variation was 22.5 mg/l (June, 1960).

Vertical distributions of dissolved oxygen concentration were not studied at station H because of atypical vertical mixing which was caused by the outfall structure. Such data are available only for station E where from July 21, 1960, through July 28, 1961, 32 observations were made.

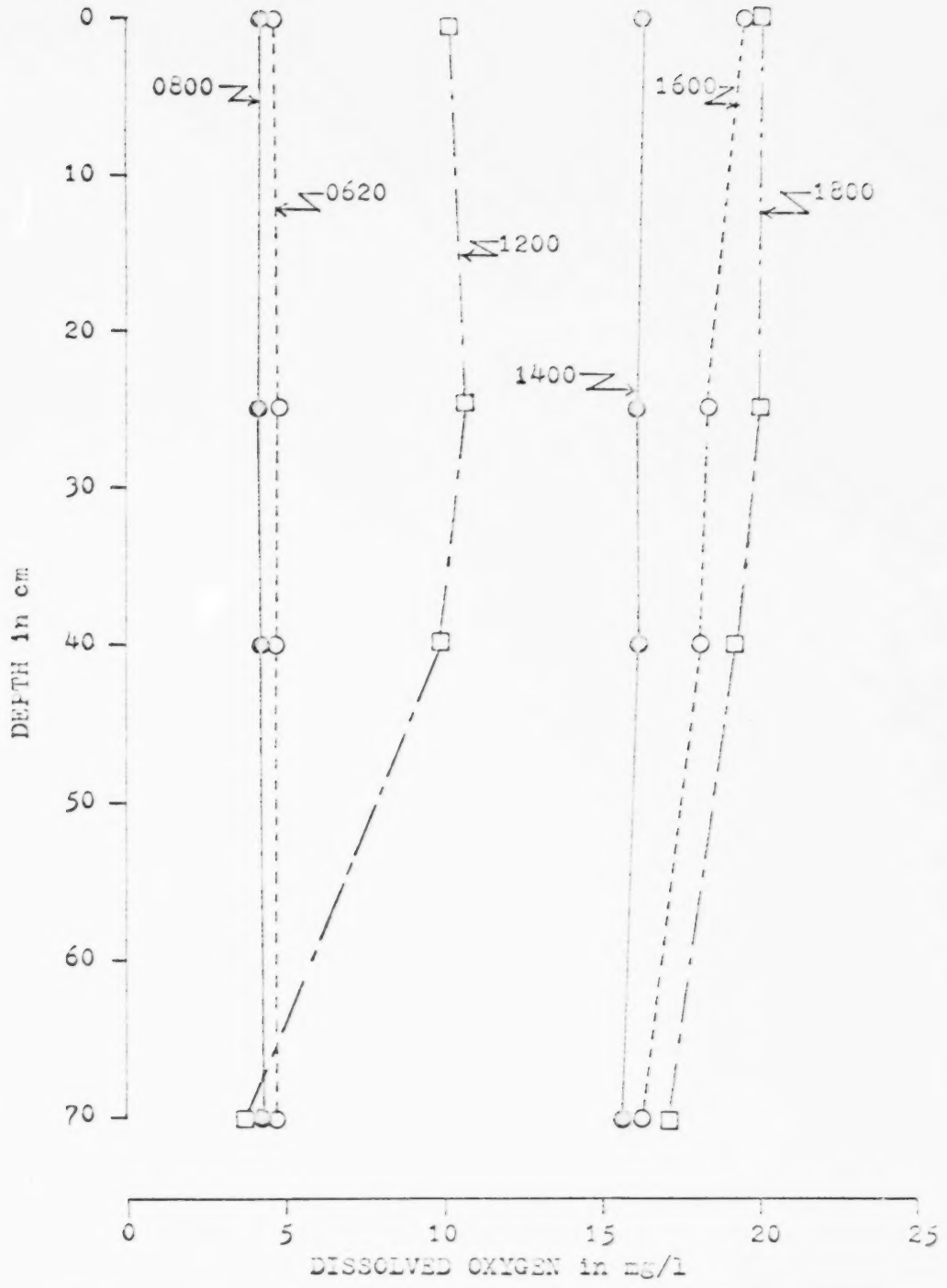



Figure 23.--Selected example showing vertical distribution of dissolved oxygen at different hours at station E, in the sewage oxidation pond, Arcata, California.

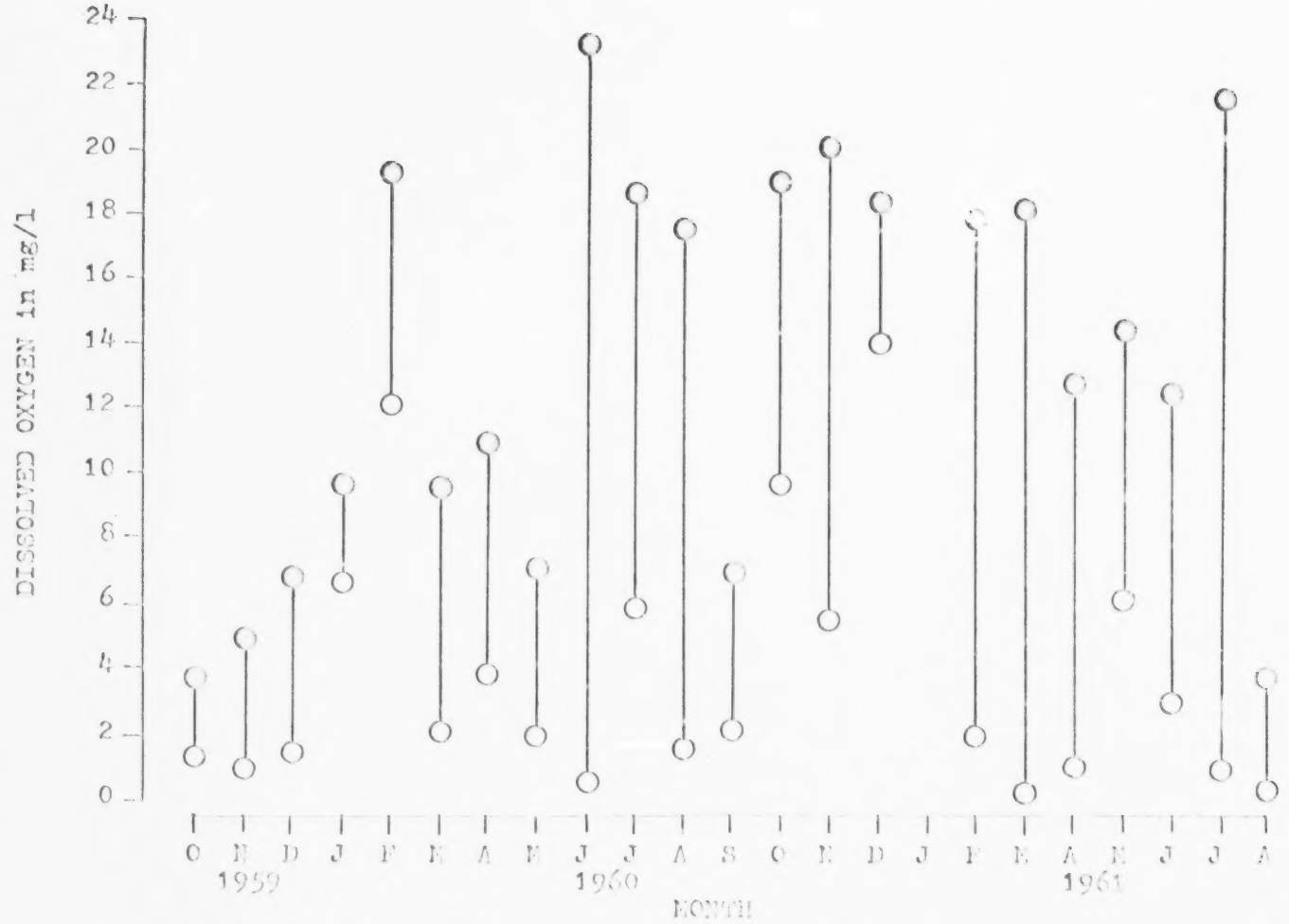



Figure 24.--Monthly maximum and minimum Kemmerer depth dissolved oxygen observations at station E, in the sewage oxidation pond, Arvin, California.

During this period instantaneous vertical differences were found to range from 0.1 to 9.4 mg/l. Typical examples are included in Figure 25.

Monthly maximum and minimum observed per cent of air saturation values of dissolved oxygen at station H ranged from 1.0 to 256.1 per cent (Figure 26). The data suggest that a seasonal pattern in Kemmerer depth dissolved oxygen does not exist in the Arcata oxidation pond. The observed per cent of air saturation values were distributed about equally above and below 100 per cent during both winter and summer months.

## Alkalinity

### General

During the period June 3, 1960, and August 3, 1961, 216 total (methyl orange) and 114 phenolphthalein alkalinity determinations were made. Total alkalinity ranged from 121.0 mg/l to 296.0 mg/l. The minimum observed was at station H (on March 28, 1961); the maximum was at station A (on September 30, 1960). The maximum range for any one month was 73.0 mg/l (September, 1960) and the monthly mean range was 35.8 mg/l. The minimum and maximum levels of phenolphthalein alkalinity were observed at station H. These were 4.9 mg/l (on December 9, 1960) and 47.1 mg/l (on July 12, 1960).

Monthly maximum, minimum and mean levels of both forms of alkalinity are summarized in Appendix H.

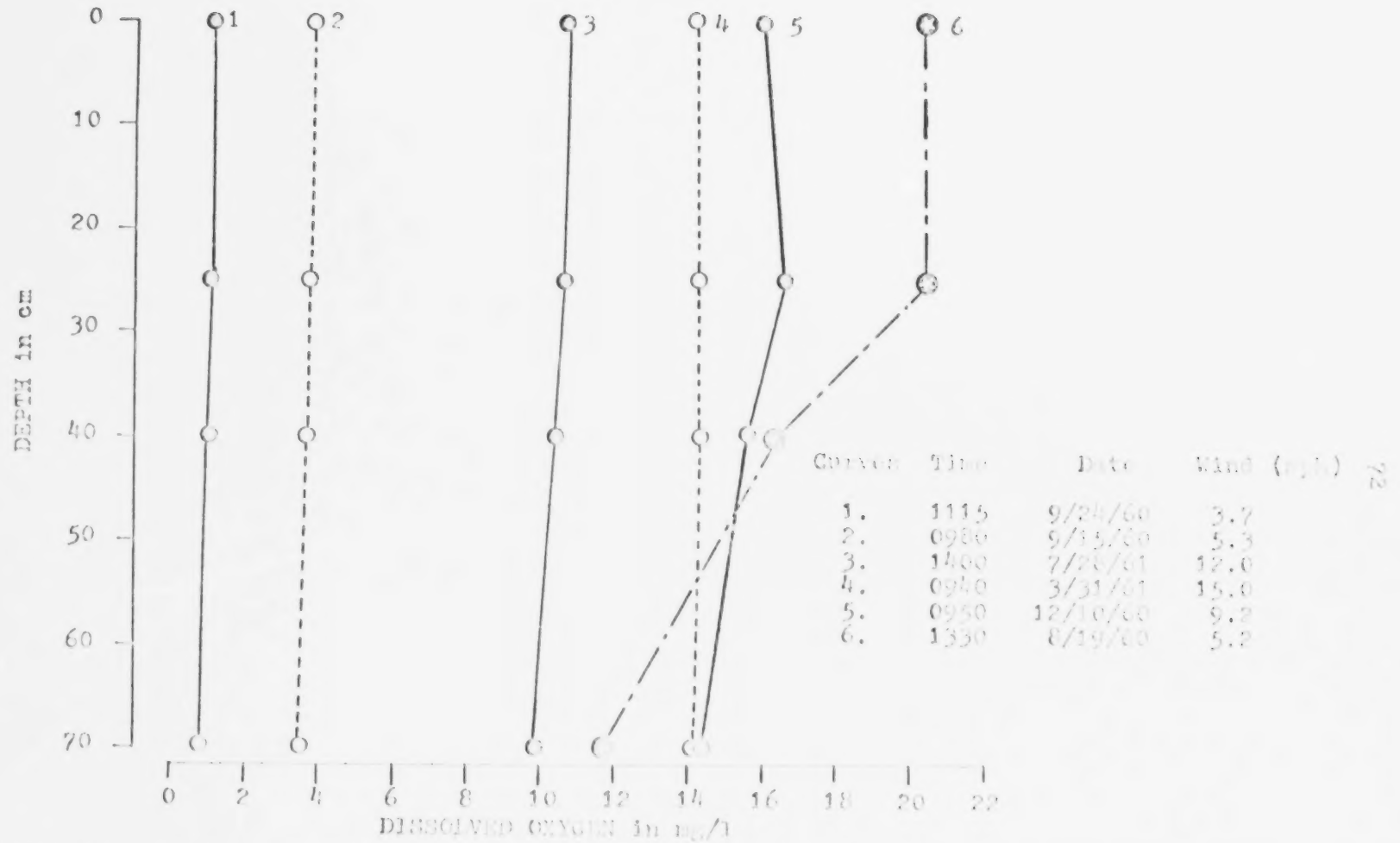



Figure 25.--Selected examples showing vertical distribution of dissolved oxygen at station E, in the sewage oxidation pond, Arcata, California.

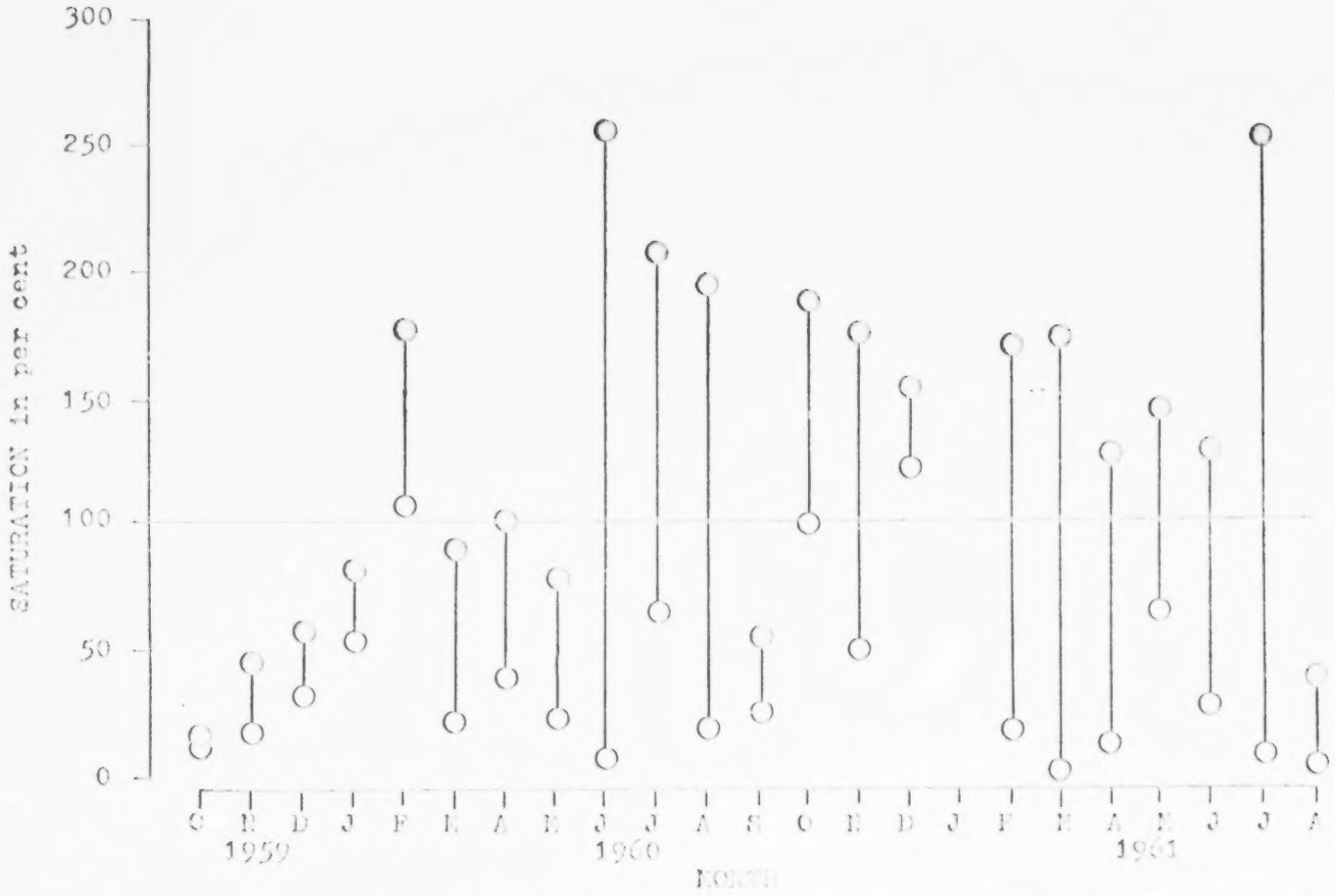



Figure 26.--Monthly maximum and minimum five-foot depth dissolved oxygen saturation values at station H, in the sewage oxidation pond, Arcata, California.

Differences Among Stations

Differences in total alkalinity among stations sampled within the same time interval show that levels among stations differed by a minimum of 0.3 mg/l (on August 4, 1960 and February 25, 1961) to a maximum of 38.5 mg/l (on June 27, 1960) (Figure 27). The mean difference for all observations was 6.4 mg/l. Concentrations at station H were found to differ from the other stations at any one time by not less than 0.3 mg/l nor more than 37.5 mg/l.

The phenolphthalein alkalinity among all sampled stations differed by a minimum of 1.2 mg/l (on July 18, 1960) to a maximum of 20.8 mg/l (on August 1, 1960) (Figure 28). The mean difference for all observations was 5.3 mg/l. Station H phenolphthalein alkalinity concentrations were found to differ from the other stations at any one time by as much as 20.8 mg/l.

Representative Diurnal Patterns

During the study eleven diurnal cycles of total alkalinity levels at station H were determined. On three occasions phenolphthalein alkalinity observations were included. These observations showed that the daily range of concentrations were as great as 42.0 mg/l for phenolphthalein alkalinity and 21.0 mg/l for total alkalinity. Generally, however, the total alkalinity range was less than 4.0 mg/l.

Typical diurnal patterns show that phenolphthalein alkalinity follows a pronounced diurnal pattern of change,

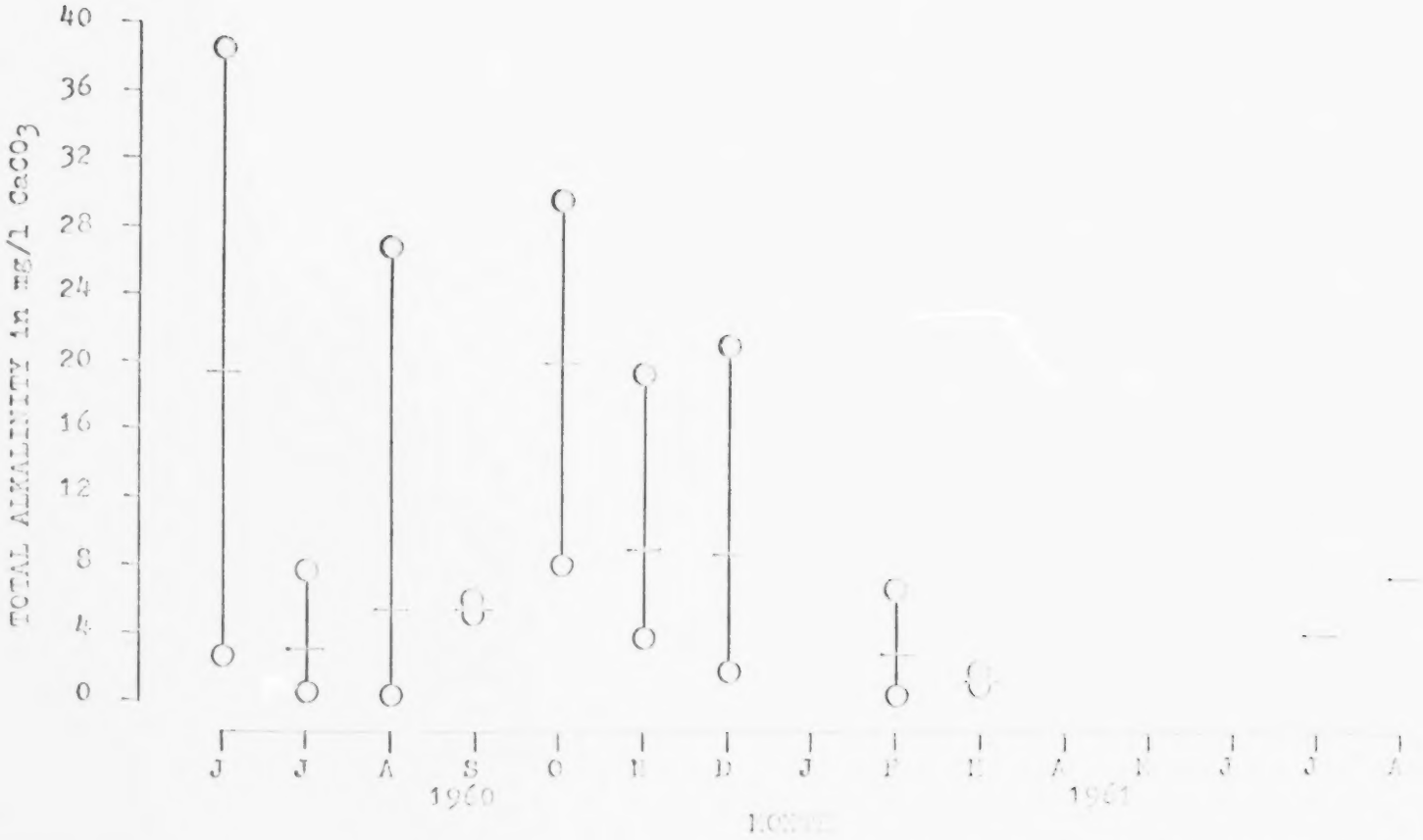



Figure 27.--Maximum, minimum and mean differences in total alkalinity (mg/l $CaCO_3$) among stations in the sewage oxidation pond, Arcata, California.

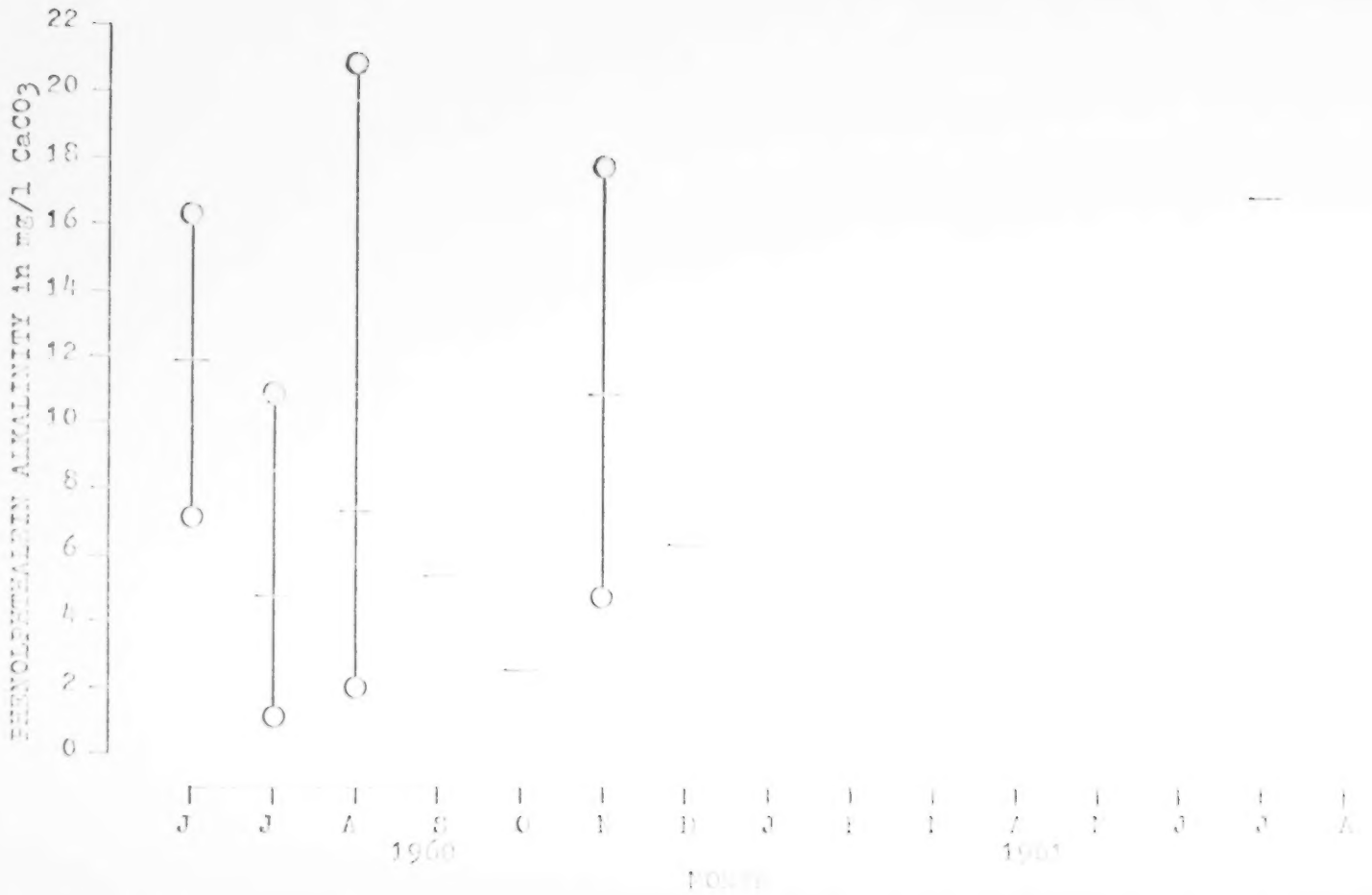



Figure 20.—Station, minimum and mean differences in phenolphthalein alkalinity among stations in the range of Bullfrog pool, Arizona, California.

Whereas total alkalinity remains [illegible] (Figure 29 and 30). The phenolphthalein [illegible] alkalinity increased in concentration from early morning until late afternoon, it declined during the hours of darkness. During the July 12-13 period, the diurnal range of phenolphthalein alkalinity was 42.0 mg/l and during the July 22-23 period the difference was 18.9 mg/l. The diurnal range of total alkalinity, on the other hand, although variable, remained less than 4.0 mg/l.

Representative Seasonal Pattern

Monthly maximum, minimum and mean alkalinity levels observed at station A during the period June, 1960 through August, 1961 will serve to illustrate the general seasonal pattern of alkalinity change in the pond.

A pronounced pattern of total alkalinity is evident (Figure 31). Minimum concentrations were observed in the early spring (March-April) following which there was a steady increase in concentration until the peak was reached in late fall (October-November). Thereafter, the concentration decreased to early spring levels. Levels ranged from a minimum of 115.1 mg/l (on March 30, 1961) to a maximum of 271.2 mg/l (on November 5, 1960).

There is a suggestion of a seasonal pattern of phenolphthalein alkalinity with high levels appearing in the spring and summer months and low levels appearing in the winter months (Figure 32). Levels ranged from a minimum of 3.6 mg/l (on April 7, 1961) to a maximum of 47.1 mg/l (on July 12, 1961).

Figure 29.--Diurnal variation in alkalinity in Antelope Lake, Arizona, on July 12-13, 1961, at an inflow site, in the epilimnion, and in the hypolimnion.

Figure 30. - Alkalinity titration curves of a water containing carbonate and bicarbonate.

TOTAL ALKALINITY in mg/l CaCO3
280
260
240
220
200
180
160
140
120
100

50
45
40
35
30
25
20
15
10
5
0

## Nitrogen

### General

A few observations on the concentration of ammonia, organic, nitrate and nitrite nitrogen at the pond inlet were made from July through November, 1961 (Table 10). Only one observation was made during any one day and efforts were not made to collect samples at the same time of day on different days.

### Ammonia Nitrogen

Twenty-two determinations of ammonia nitrogen concentration were made between July 5, and November 17, 1961. The maximum concentration observed was 2.23 mg/l (on October 13) and the minimum was 0.55 mg/l (on October 10). The overall range was 1.68 mg/l. No regular pattern of concentration change was apparent.

### Organic Nitrogen

Twenty determinations of organic nitrogen were made between August 17 and November 17, 1961. The maximum concentration observed was 11.28 mg/l (on October 30) and the minimum was 4.30 (on August 29).

### Nitrate Nitrogen

Twenty-five determinations of nitrate ion were made between August 9 and November 17, 1961. The maximum concentration was 0.26 mg/l (on October 10) and the minimum was 0.18 mg/l (on September 7). No seasonal pattern of change was indicated.

Table 10.--[illegible]

| Item | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Nitrite Nitrogen

Twenty-two determinations of nitrite ion were made between August 16, and November 17, 1961. The maximum concentration was 0.080 mg/l (on August 16) and the minimum was 0.033 mg/l (on October 16). No regular pattern of change in concentration was evident.

## Biochemical Oxygen Demand

General

The rate (k) at which the clarifier supernatant was being oxidized by bacterial activity was calculated to be 0.22. The calculation was made in accordance with the method described by Moore, Thomas and Snow (1950).

Pond Influent (Clarifier Effluent)

General--A total of 41 determinations of pond effluent 5-day B.O.D. were made between August 10, 1960 and July 29, 1961 (Appendix I). B.O.D. values ranged from 26 mg/l (on April 27, 1961) to 267 mg/l on July 29, 1961. The mean B.O.D. was 115 mg/l.

Diurnal Pattern--Four sets of diurnal observations were taken during the study (Figure 33). The data indicates that diurnal changes at the clarifier can be considerable. The maximum change was 187 mg/l (on July 28-29, 1961) and the minimum was 65 mg/l (on March 22-23, 1961). There is a tendency for B.O.D. to become depressed during the late evening-early morning hours and accentuated during the remaining portion of the day.

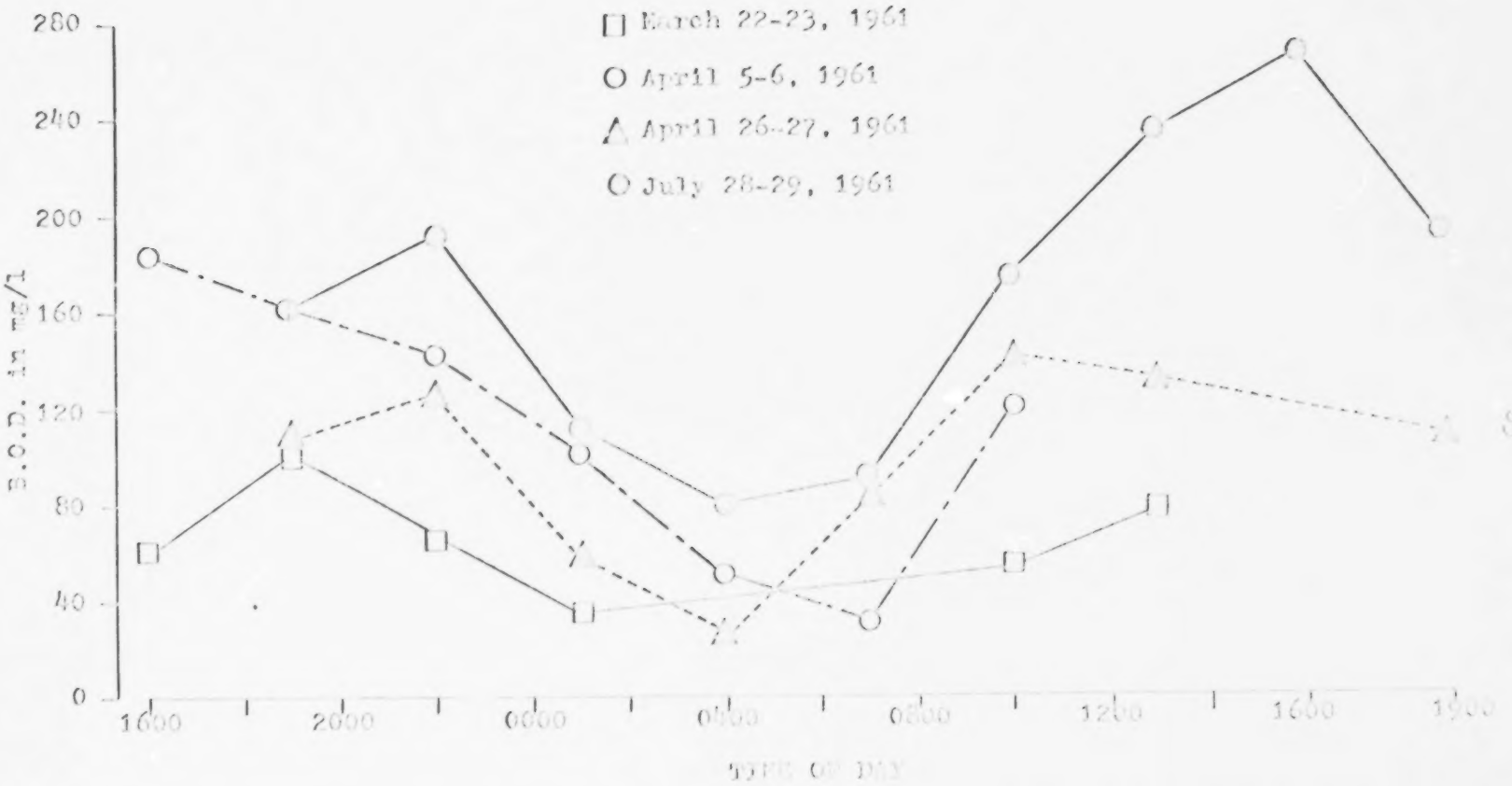



Figure 33.—Selected examples showing diurnal B.O.D. pattern at the sewage treatment clarifier, Arcata, California.

Seasonal Changes--Since hourly differences in diurnal B.O.D. are often considerable any attempt to demonstrate seasonal differences must be based on comparable observation times. Comparable B.O.D. observations were taken at 1000, 1500, and 1600 hours (Figure 34). These data suggest a seasonal pattern. The higher B.O.D. values were recorded during the dry months whereas the lower B.O.D. values were recorded during the wet months.

Outfall Effluent

General--A total of 34 observations representing 15 different days were taken at the outfall (station E) between August 17, 1960 and August 3, 1961 (Appendix C). Outfall B.O.D. values ranged from 5 mg/l (on October 2, 1960) to 28 mg/l (on July 22, 1961). The mean B.O.D. was 16 mg/l.

Diurnal Pattern--Four sets of diurnal observations were taken during the latter stages of the study program (Figure 35). These data represent summer conditions only. Three of the data sets show that there is a tendency for B.O.D. to become depressed during hours of darkness and accentuated during daylight hours. However, for some unknown reason(s) the observations taken during July 22-23 show a contrary pattern. Diurnal differences varied from 7 to 10 mg/l. The mean difference was 8.25 mg/l.

Seasonal Changes--No seasonal pattern of change was evident.

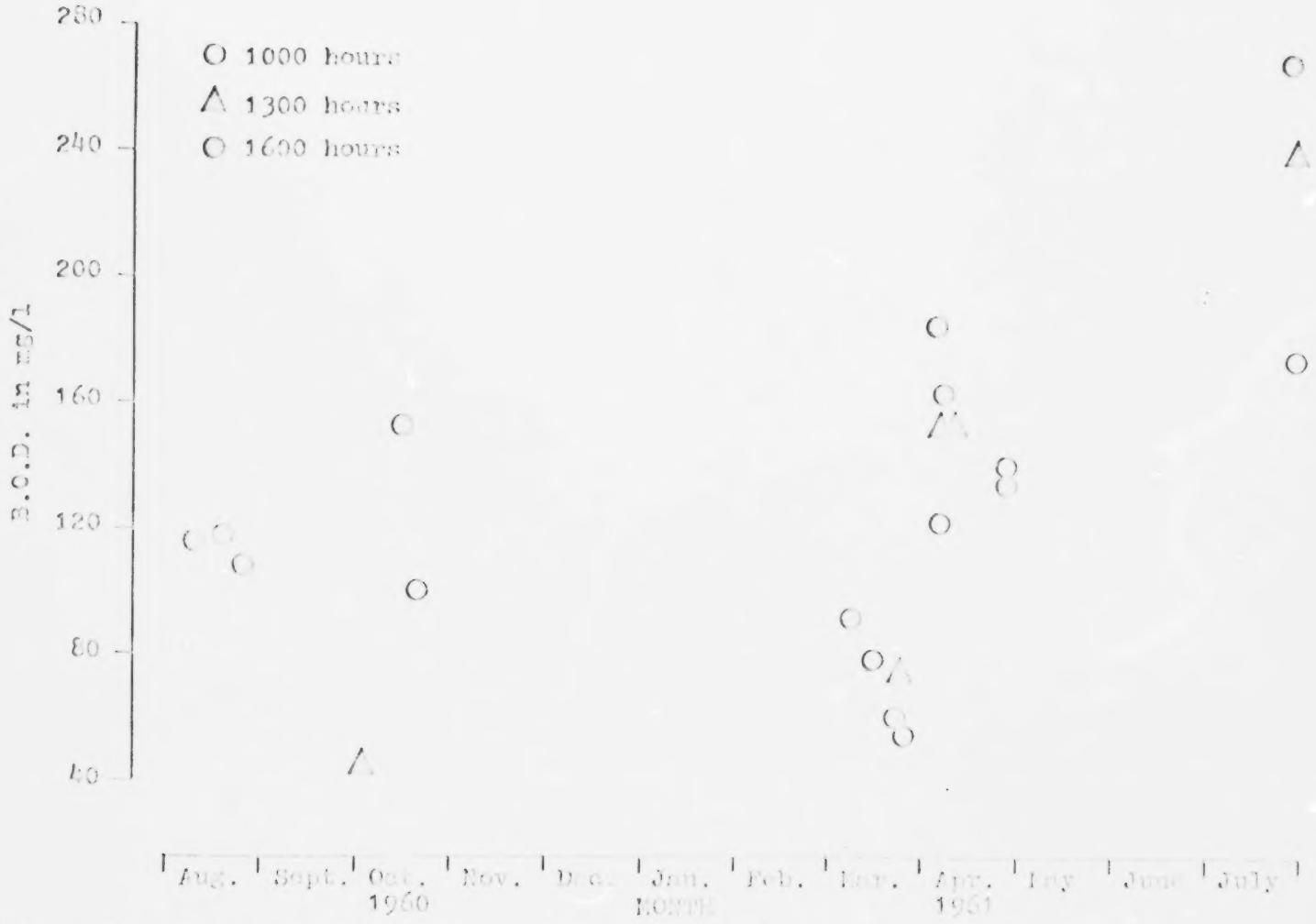



Figure 3.--Seasonal distribution of B.O.D. observations taken at selected hours at the sewage treatment plant clarifier, Arcata, California.

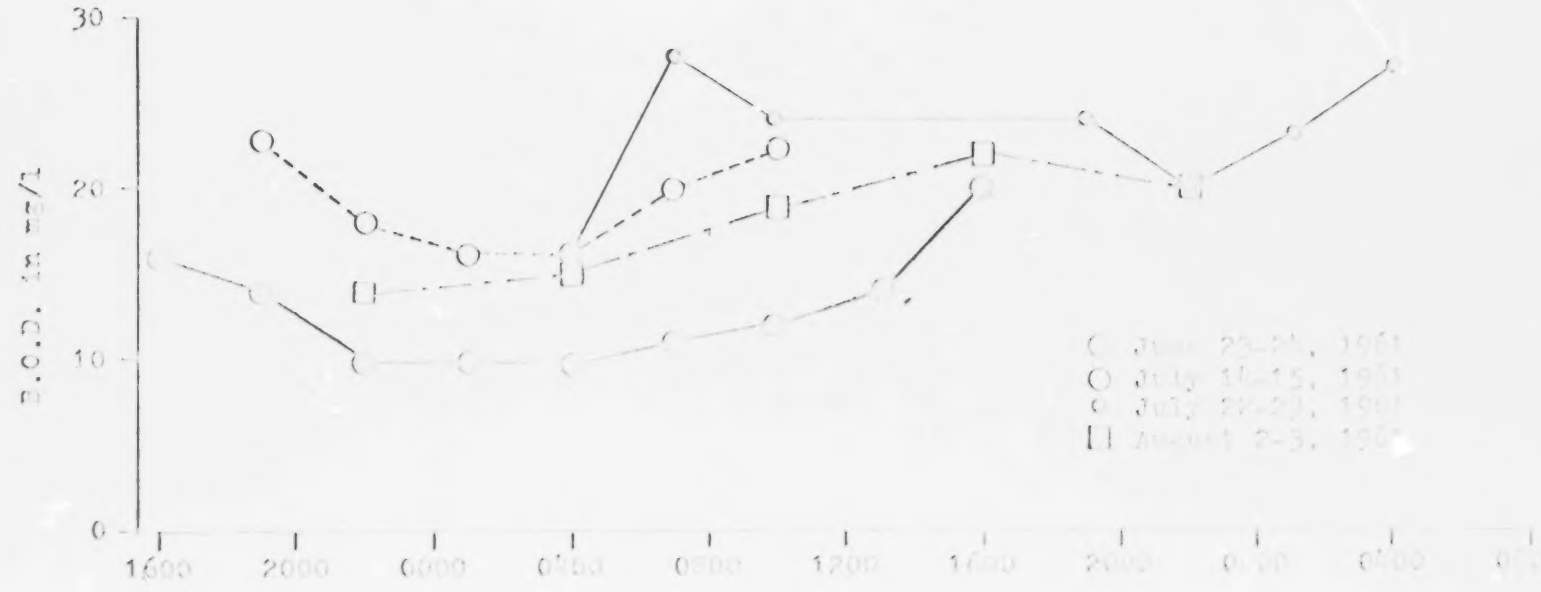



Figure 35.--Selected complex showing diurnal pattern of B.O.D. at station 2 in the raw sewage oxidation pond, Arcata, California.

## IV. DISCUSSION

### A. PHYSICAL FEATURES

The primary objective of this study was to ascertain certain chemical and physical features of the Arcata, California sewage oxidation pond to obtain background information for assessing future changes in pond conditions. An effort was made to obtain extreme values of each variable encountered, but because the time of sampling varied from day to day, except for more conscientious users to be cautious that the extremes observed were always the actual extremes that existed.

Although data on a few of the studied features were limited and permit only tentative interpretations at best, most of the data contributes greatly to a better understanding of the conditions of a sewage oxidation pond in a temperate, maritime climate. With the exception of some differences due to geographical location and attendant climatological conditions, the chemical and physical quality of the Arcata pond was found to be generally similar to that of a number of other ponds that have been described in various papers such as those by Downe, et al. (1957), Noel, et al. (1961) and Borges and Mackenthun (1963).

Temperature

Surface temperatures were fairly uniform throughout the Arcata pond at any given moment. Diurnal differences of 3°C.

or more occurred. The tendency of Arcata pond surface temperature to change with air temperature is a characteristic pattern of ponds in general. According to Welch (1952) pond waters tend to follow air temperature because of their shallow depths and their large expanses of surface as compared with their volumes. Heat to the surface of the pond is gained primarily by insolation (the penetration of solar radiation and its absorption by the water). Heat losses at the surface occur primarily from evaporation and back-radiation.

Vertical differences in temperature were not studied to any great extent in the present study but Towne, et al. (1957) reported data that probably can be applied here. These authors stated that temperature differences of 5°C. from surface to bottom may develop within a pond depth of 3½ feet during warm, calm days. Such a temperature gradient generally is formed during the morning hours and as a rule disappears during the evening hours or during high winds. Wind, of course, is the chief factor by which heat absorbed at and near the surface is distributed to depths below which much radiant energy can penetrate directly. The limited data collected during this study agree with these observations. Thus, surface temperatures taken during or following strong wind activity or in the evening most likely were near the mean temperature of the pond at that time.

One of the important functions of temperature in an oxidation pond is its influence on algal metabolism. It may

Low transparencies resulting from high algal densities probably had little or no adverse effect upon the operation of the Arcata pond even though at the time much of the pond's volume was not participating in oxygen production. Most likely, adequate supplies of dissolved oxygen produced in the euphotic zone were transported toward the bottom of the pond by wind-generated currents, thus enabling aerobic stabilization to take place below the lighted zone.

Specific Electrical Conductance

Conductivity measurements were taken during the early part of this study partly as a means of detecting the extent of salt water intrusion into the pond from Humboldt Bay and partly to obtain an index to the total concentration of ions in the pond water. During the fall and winter months of 1959-60, salt water intrusion into the Arcata pond was suspected because the flap gate on the outfall line occasionally failed to close properly and because effluent flows were sometimes inadequate to act as an effective barrier to entering bay waters. Before the first fall rains conductivity readings were greater than 3000 mmhos/cm and on one occasion had reached a value of 4255 mmhos/cm. A progressive decline in the conductivity of the pond developed following the beginning of the fall rains. The decline which continued into the spring months was believed caused by: (1) accretion of storm water which affected a dilution of the mineral quality of the pond and (2) repair of the faulty outfall structure which may have prevented much additional bay water from entering

the pond. By June, conductivity values were less than 900 mmhos/cm.

According to McKee and Wolf (1963) conductivity in mmhos/cm times 0.65 is approximately equal to the concentration of total dissolved solids in mg/l. Using this conversion factor, total dissolved solid concentration data from four oxidation pond studies were used to obtain the representative conductivity values (Table 11). These conversions suggest that the general conductivity range in a sewage oxidation pond receiving clarified sewage is between 500 and 2000 mmhos/cm. Values in excess of 2000 mmhos/cm probably are attributable to extraneous sources. For purposes of this study, conductivities in the Arcata pond in excess of 2000 mmhos/cm are ascribed to salt water intrusion from Humboldt Bay.

The intrusion of salt water that apparently occurred may have had a significant local effect on algae in the pond. Since the chief source of dissolved oxygen in an oxidation pond is algal photosynthesis, oxygen concentration at station H was used as an indicator of the presence of salt water (Figure 36). The selected oxygen concentrations were observed in the daytime and for the most part represent the maximum concentrations observed during the day. The curve indicates that when conductivity values were above 2000 mmhos/cm, dissolved oxygen levels remained low throughout the entire diurnal period. Conversely, when conductivity values were less than 2000 mmhos/cm, afternoon dissolved oxygen

Table 11.--Relative conductivity values (in mmhos/cm) from four oxidation pond studies.[a/]

| Reference | Study Period | Pond Location | Specific Conductance Mean Influent | Mean Effluent | Range Influent | Range Effluent |
|---|---|---|---|---|---|---|
| Silva and Papenfuss, 1953. | 10/51-8/52 | Concord, Calif. | 1435 | 1541 | 1037-1900 | 1146-1820 |
| Gotaas, et al., 1954 a. | 1/53-12/54 | Richmond, Calif. | 707 | 634 | 520-972 | 495-749 |
| Allen, 1955. | 7/53-4/54 | Concord, Calif. | 1114 | 1063 | 902-1591 | 957-1449 |
| Oswald, 1959. | 2/57-5/57 | Concord, Calif. | -- | 1418 | -- -- | 1391-1434 |

[a/] Conductivity values calculated from the formula: conductivity in mmhos/cm = total dissolved solids in mg/l ÷ 0.65.

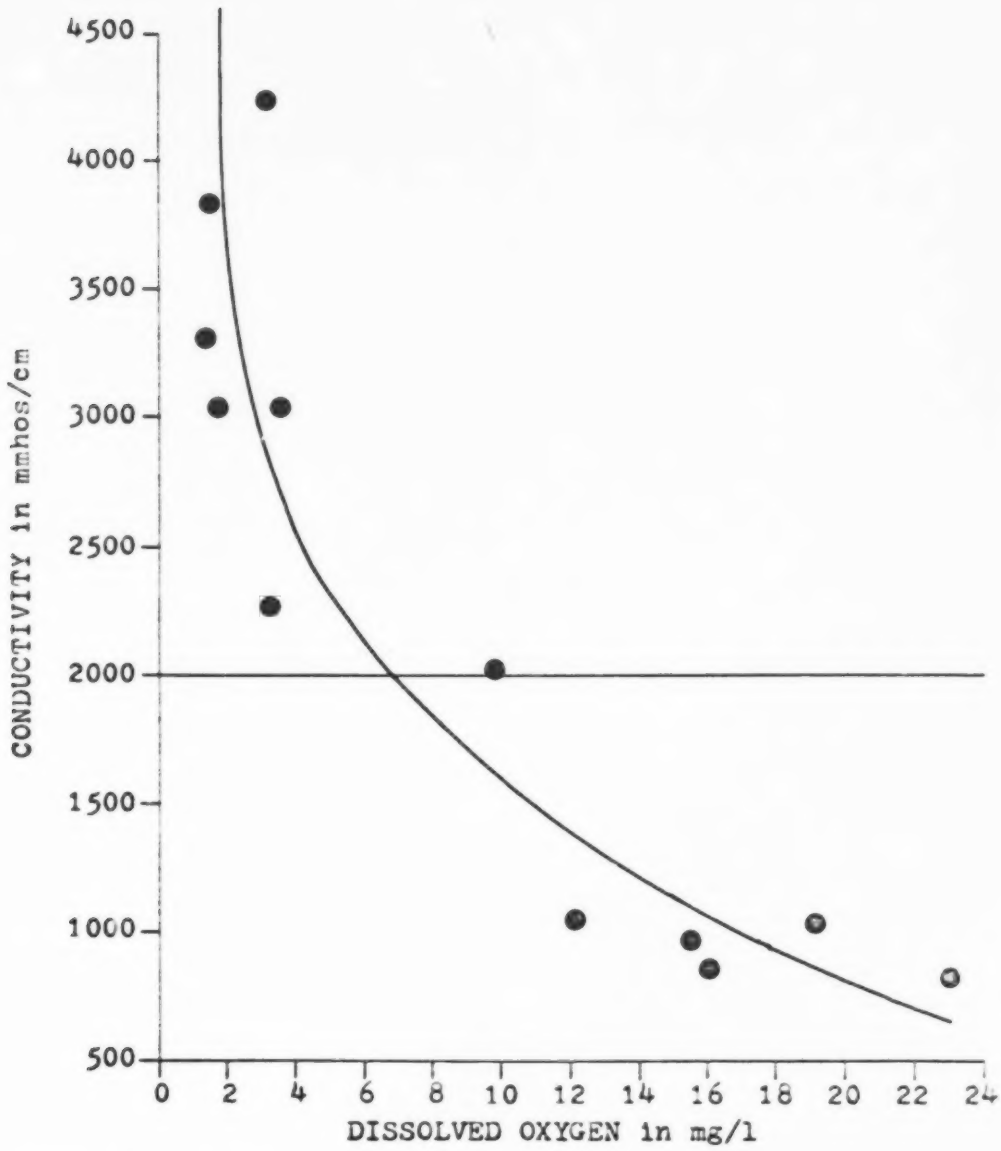



**Figure 36.--Influence of conductivity on algal photosynthesis as indicated by dissolved oxygen levels at station H in the sewage oxidation pond, Arcata, California. Conductivities above 2000 mmhos/cm are attributed to salt water intrusion.**

values tended to be high. It is evident that photosynthetic activity was depressed by conductivities in excess of 2000 mmhos/cm. Thus, these data indicate that salt water intrusion did occur and sometimes did have an adverse effect on pond conditions.

Dissolved Oxygen

Dissolved oxygen is the key to efficient and odorless waste treatment in a sewage oxidation pond. The levels of dissolved oxygen in an oxidation pond are a result of interactions among many chemical, physical and biological factors. These factors include sunlight, temperature, nutrient concentration, wind, water currents, B.O.D., algae and zooplankton. For the most part, the chemical and physical factors provide the mechanisms by which oxygen is introduced and dispersed. These factors also control or regulate the biological factors that are responsible for oxygen production and most utilization.

The vertical distribution of dissolved oxygen at a given location in the Arcata sewage oxidation pond appeared to be related to the general level of dissolved oxygen in the upper layers and wind activity. Great vertical differences appeared when the concentration of dissolved oxygen exceeded 100 per cent of the air-saturation value and wind conditions were calm. Almost complete vertical uniformity developed when concentrations were below 100 per cent of the air saturation value and when wind activity was high. Oxygen in the lower depths must have come mainly from the

surface layer through wind action and/or by diffusion since Hazel (1963) found that oxygen production in the Arcata pond was restricted generally to the upper 50 cm of depth. McNabb (1960) found that the vertical distribution of oxygen in a pond depended principally upon the degree to which the water was mixed by wind-induced currents. He concluded that diffusion of oxygen along vertical gradients was very slow and of little consequence in supplying oxygen to the lower portion of a pond.

A distinct seasonal pattern of oxygen concentration was not detected in the Arcata pond. High dissolved oxygen concentrations existed at times during all seasons of the year as did very low concentrations.

The primary source of dissolved oxygen in an oxidation pond is algal photosynthesis and any factor which limits the size of the algal population or its ability to carry on photosynthesis would indirectly curtail the production of dissolved oxygen in the pond. Prolonged periods of low dissolved oxygen production would, of course, result in unsatisfactory waste stabilization. The influence of some chemical and physical factors on algal production is well-known but the effect of "grazing" by zooplankters on the abundance of algae is not so well understood. Hazel (1963) concluded that probably the most important single cause of anaerobic conditions in the open water of the Arcata pond was the over-grazing of algae by Daphnia. He compared Daphnia abundance and Chlorophyll a concentration against

time. Curves fitted to the plotted points showed a cyclic pattern apparently related in a "predator-prey" fashion. By constructing a curve from the highest dissolved oxygen values observed at station H between the hours of 1000 and 1800 during the summer of 1960 and plotting it with Hazel's curves, a relationship between Daphnia abundance, Chlorophyll concentration and dissolved oxygen concentration is established (Figure 37). It is clearly evident that grazing of algae by Daphnia exerted a profound effect on the dissolved oxygen levels of the pond.

Alkalinity and Hydrogen Ion Concentration

Relationships between the various forms of alkalinity and photosynthesis and respiration-decomposition in the Arcata pond were analyzed. The general relationships observed in the pond have already been described for other oxidation ponds by Neel, et al. (1961). In photosynthesis, algae remove carbon dioxide in the form of carbonic acid from the water. When all the acid has been taken up by this means, the algae may utilize bicarbonate ion as the source of carbon dioxide. Photosynthesis thus can bring about an alteration in the relative amounts of soluble (unbound) carbonic acid, intermediately soluble (half bound) bicarbonates and the nearly soluble (bound) monocarbonates in the water, even though total alkalinity remains nearly constant. Decomposition-respiration on the other hand, restores lost normal carbonate back into solution as calcium bicarbonate.

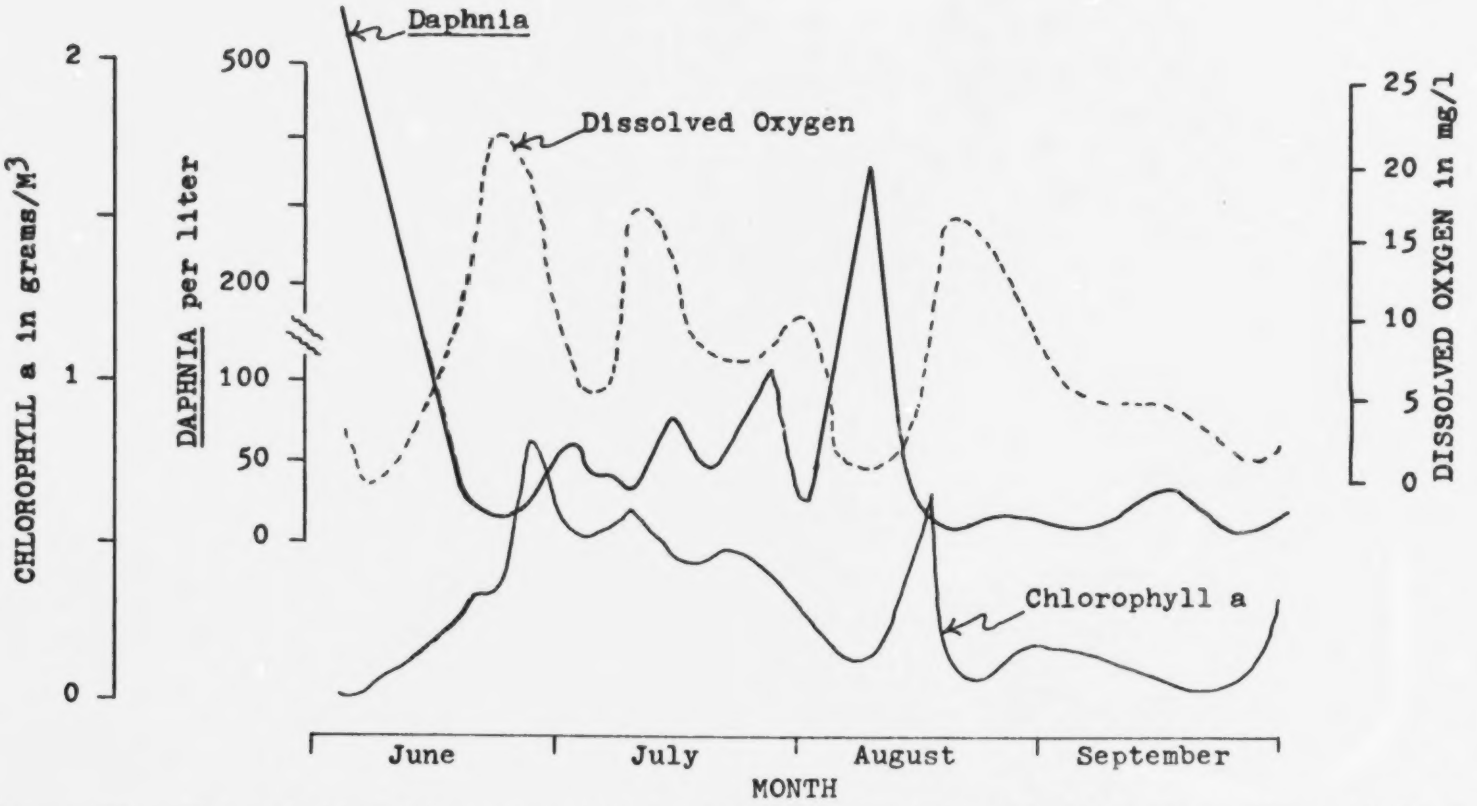



Figure 37.--The relationship among the concentration of dissolved oxygen, Chlorophyll a and Daphnia magna during the summer of 1960. Chlorophyll a and Daphnia curves modified after Hazel, (1963).

Alkalinity and pH conditions for a single representative day in the Arcata pond are compared in Figure 38. Bicarbonate alkalinity underwent a progressive decline from morning to night whereas carbonate alkalinity exhibited a progressive increase. Reverse changes occurred from dark until the next morning. Total alkalinity remained nearly constant throughout the 24-hour period.

Total alkalinity showed a definite seasonal pattern in the Arcata pond. Following the last spring rains and continuing through the dry summer and early fall months total alkalinity gradually increased. The abrupt decrease in December is associated with the large influx of low alkalinity storm runoff water that the pond received. This cyclic pattern is characteristic of many highly entrophic waters. According to Phinney and Peek (1960) total alkalinity increases during intense algal activity as a result of hydroxyl-ion exchange from photosynthesis which depletes the hydrogen-ion supply. During the winter months, the reverse process dominates as a result of dilution flows and reduced photosynthesis.

pH measurements were important in this study because they are an indicator of the chemical and biological activity in water (Silva and Papenfuss, 1953). In a sewage oxidation pond pH is largely a measure of the amount of dissociated carbonic acid. The removal through photosynthesis during daylight hours of carbon dioxide first as free carbon dioxide and later as bicarbonate causes an increase in pH as shown in

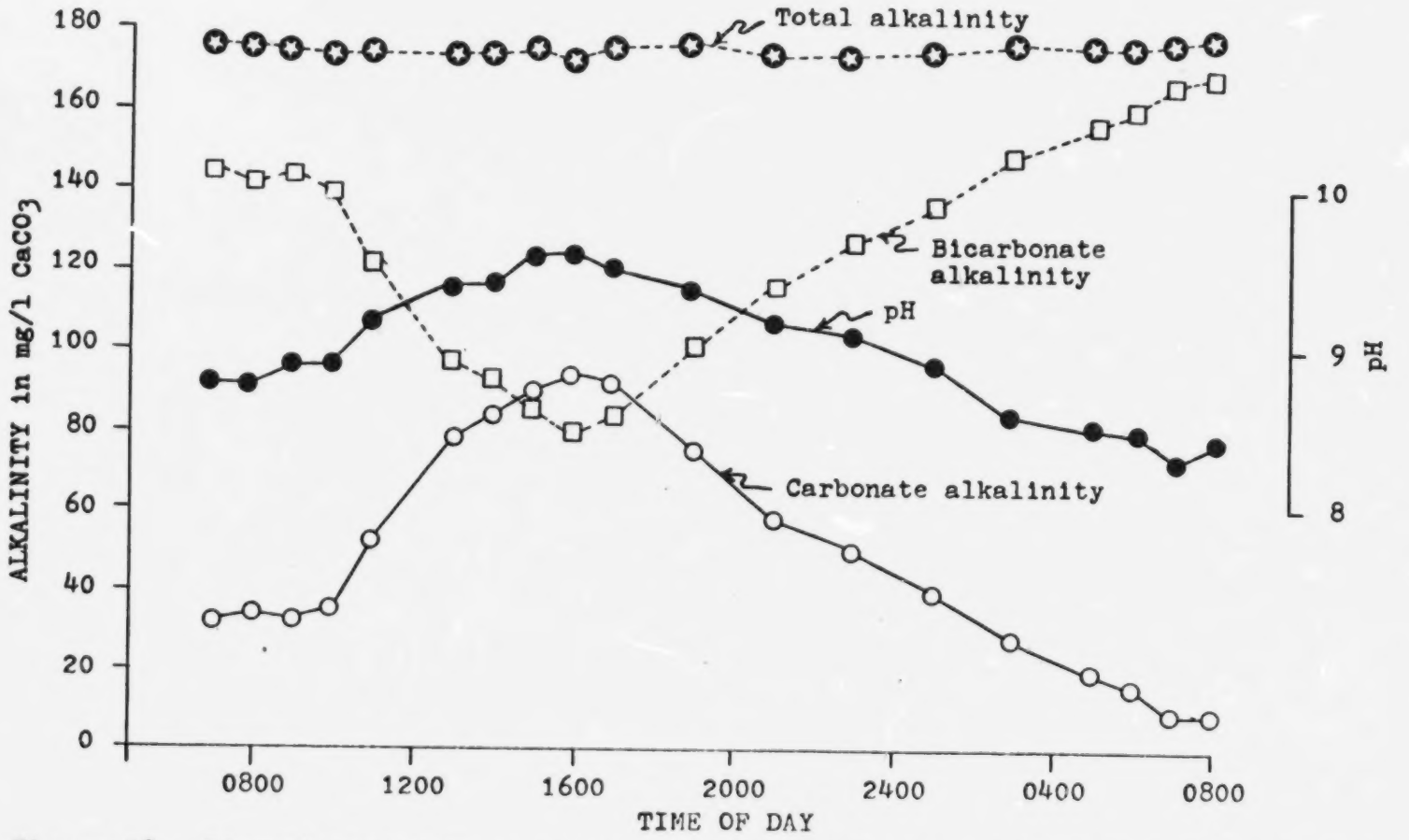



Figure 38.--Diurnal variation in carbonate, bicarbonate and total alkalinity and pH during July 12-13, 1961, at station H in the sewage oxidation pond, Arcata, California. Carbonate and bicarbonate values were converted from total and phenolphthalein alkalinity observations in accordance with the procedure described in Standard Methods (1960).

Figure 38. During the night as carbon dioxide is being furnished by respiration and decomposition, the pH decreases. Based on information on other ponds by Neel, et al. (1961), the pH values above 8.0 must have been produced by a photosynthetic rate that demanded more carbon dioxide than the quantities furnished by respiration and decomposition.

Nitrogen

The concentrations of organic, ammonia, and nitrate nitrogen observed in the Arcata pond were almost identical to those reported by Neel, et al. (ibid.) for effluents from other oxidation ponds. There was much more organic and ammonia nitrogen than nitrate or nitrite. In the present study not enough data were obtained to detect the possible presence of seasonal patterns of concentration in any form. Neel, et al. (ibid.) found no apparent seasonal pattern in the concentration of nitrogen. The levels for any one month were related to degree of photosynthetic activity and not necessarily to season.

A large share of the organic nitrogen present in the sewage normally is converted into ammonia nitrogen by the time the waste enters an oxidation pond. Thus, in the oxidation pond the concentrations of organic and ammonia nitrogen were about the same. This is important since algae can readily utilize ammonia but not organic nitrogen. Very little organic nitrogen is used by algae since they must compete with bacteria for the available supply (Gotaas and Oswald, 1957). The low nitrate and nitrite concentrations

observed are attributed to two main causes. In the first place, nitrate and nitrite concentrations normally are low in raw and clarified sewages. Secondly, once the waste enters an oxidation pond the nitrification of ammonia normally is limited by its rapid uptake by algae.

Biochemical Oxygen Demand

Sewage flow and B.O.D. to the Arcata sewage oxidation pond exhibited wide fluctuations; both diurnally and seasonally. In terms of diurnal variation and monthly ranges, these observations show a close similarity to those reported by Allen (1955) at Santa Rosa, California. The wide variations are attributed to the combined effects of differential use of the sewage disposal system and ground water infiltration. As a result of these factors the B.O.D. of the clarified inflow was greater during the dry months than during the wet months and greater at noon than at any other time of day.

A value of k was calculated to give an indication of the relative rate of bacterial oxygen utilization. The larger the value of k the more rapid the rate of oxygen utilization. The rate of 0.22 obtained in this study is characteristic of k values of fresh supernatants (Moore, et al., 1950).

The influent B.O.D. is a measure of pond loading and is generally expressed in terms of pounds of B.O.D. per surface acre per day (lbs. B.O.D./S.A./day). Because the B.O.D. of clarified sewage varied with the time of day it was necessary

to calculate a mean B.O.D. value and use it as a measure of loading for that day. Thus, in this study only diurnal observations were used to determine loading values. From these data pond loadings were calculated to range from 15 to 28 lbs. B.O.D./S.A./day with a mean loading of 22 lbs. B.O.D./S.A./day. The calculated values appear to be reasonable and fall somewhat in line with those reported for similar oxidation pond facilities (Bartsch and Allum, 1957; Neel, et al., 1961).

The B.O.D. at the outfall showed some seasonal and diurnal variation but not as pronounced as the inflow B.O.D. The low B.O.D. values during the winter months resulted principally from storm water dilution. The diurnal pattern is particularly interesting since the higher values generally occurred during the daylight hours. This phenomenon is attributed to the response of algae to light. In reviewing the literature, Hazel (1963) found that Euglena tends to migrate toward the zone of optimum light intensity. Thus, during the daylight hours the motile algae concentrate toward the surface of the pond. Surface samples collected at this time included numerous algal cells, which, under the conditions of the 5-day B.O.D. test, provided an additional contribution to the B.O.D. of the sample. At night, however, due to the absence of light, the cells were distributed somewhat uniformly from surface to bottom. Surface samples collected at this time contained fewer algal cells and consequently had a lower B.O.D.

The B.O.D. values at the outfall were consistent with those reported in the literature. Bartsch (1958) states that unfiltered samples from sewage oxidation ponds commonly have a B.O.D. of about 25 mg/l.

B.O.D. reductions in the Arcata pond were obtained by rating the outfall concentration against the inflow concentration. Although the outfall B.O.D. values were not strictly comparable to the influent values for the same period because of detention times, they were of necessity used in deriving the B.O.D. reductions. Using a mean influent B.O.D. of 115 mg/l and mean outfall B.O.D. of 16 mg/l the reduction in B.O.D. was calculated at 86 per cent.

During the study, the Arcata pond was being utilized at approximately 60 per cent of its designed capacity. At capacity, mean loadings should approach 37 lbs. B.O.D./S.A./day. This loading rate, however, should have little effect on future pond performance since loadings of 50 to 100 lbs. B.O.D./S.A./day have been used successfully in similar types of ponds (Porges and Mackenthun, 1963).

## Pond Performance

The second objective of this study was to evaluate the Arcata sewage oxidation pond as a waste treatment facility. This was accomplished by determining the performance of the pond in terms of reductions in B.O.D., nutrient levels and absence of obnoxious odors and comparing these results with other waste treatment facilities.

The B.O.D. reduction in the Arcata pond compared favorably with values reported in the literature. According to Berger (1961) the best conventional secondary treatment facilities are able to reduce B.O.D. by as much as 95 per cent. Bartsch and Allum (1957) reported that B.O.D. concentration in sewage oxidation ponds are reduced in a seasonal range of 70 to 98 per cent. Thus, it is evident that the Arcata sewage oxidation pond performed well (86 per cent) not only with respect to other sewage oxidation ponds but also with other types of secondary treatment facilities.

Although nutrient reduction values are not available for the Arcata sewage oxidation pond, it appears reasonable to assume that the reduction values are not drastically different from those reported in the literature for similar types of facilities. According to Mackenthun (1962) nutrient reductions are influenced by temperature, biological activity and flow and is most pronounced at low flow and prolonged retention time. Through the activities of algae, the nutrients are removed from solution and concentrated in algal cells. In reviewing the literature Fitzgerald and Rohlich (1958) found that ammonia nitrogen may be reduced up to 90 per cent, phosphorus 96 per cent and potassium 20 per cent. Neel, et al. (1961) reported that at Fayette, Missouri, nitrogen reduction was 94-98 per cent and phosphorus reduction, 83-92 per cent. Bogan (1961) reported that 80-93 per cent phosphorus reductions are possible in the Seattle, Washington area providing that pond retention periods are

between 14 and 28 days. Inasmuch as detention periods ranged from 30 to 164 days in the Arcata pond and algal activity occurred year round, it seems reasonable to assume that nutrient reductions were maintained at relatively high levels.

From the standpoint of a closely adjacent community perhaps the best measure of oxidation pond performance is whether or not obnoxious odors are produced. It is evident from the dissolved oxygen data that the Arcata sewage oxidation pond was essentially aerobic most of the time. Occasionally zero oxygen levels were measured at various locations in the pond, although the period of oxygen depletion was sufficiently brief so that objectionable odors generally did not develop. One contrary situation, however, is worthy of mention. During the summer of 1961, oxygen production within the Arcata pond was limited by masses of floating detritus and blue green algae (Oscillatoria sp). The amount of surface covered by these floating masses varied from small patches to an estimated one-tenth of the total surface area. Dissolved oxygen measurements below the shaded surface frequently measured less than 1 mg/l. The area being shaded would vary from day to day depending on wind direction and velocities. During this period of the summer, the odor of hydrogen sulfide and methane gasses was very strong. In addition, large colonies of purple and orange bacteria were readily visible on the floating algae masses. By fall, however, these obnoxious conditions had disappeared completely from the pond.

Taking all the aforementioned facts into consideration it is concluded that the Arcata sewage oxidation pond provided good to excellent secondary treatment.

## The Pond as an Environment for Fishes

The third objective of this study was to determine the physical and chemical suitability of the Arcata sewage oxidation pond for fishes. The primary reason for considering the rearing of fishes in the Arcata pond was that fish might have some beneficial effect on the effectiveness of the pond as a sewage treatment facility through the control of Daphnia abundance. As previously indicated, Daphnia can exert a profound influence on the dissolved oxygen level of an oxidation pond and the level of oxygen is related to the efficiency of the aerobic treatment process in the pond. Although chemicals have been used to control Daphnia (Oswald, et al., 1959) fishes might provide better control since Daphnia is an important food item for many fishes. Moreover, the use of fishes for Daphnia control could provide the additional benefit of transforming a portion of the pond's productivity into a useful and retrievable form.

From June 26 to July 5, 1961, about 400,000 mosquitofish, Gambusia affinis, were transported from Cloverdale, California and liberated in the Arcata pond. The plant consisted of large, mature adult to very small (½-inch or less) fish. After being stocked their numbers declined to a low level over a period of several months, but the species

persisted and even reproduced for a period of at least two years. Mosquitofish are relatively hardy, but conditions were only marginal for them in the pond. More sensitive species such as the Pacific salmon (Oncorhynchus sp.) could not have been expected to survive for long in the pond.

Temperature and dissolved oxygen levels are the two most obvious factors which might prohibit the rearing of salmonids in the pond. These two factors are inter-related. Temperature controls the activities of fishes by regulating rates of metabolism and also the solubility of oxygen in the water. This is important since the oxygen requirements of fishes increase with a rise in temperature whereas the level of available dissolved oxygen decreases.

Brett (1960) summarized the thermal limitations required for survival and growth of the Pacific salmon at various stages of their life history. From the fry to yearling stages the temperature range for survival was approximately 1.0°C. to 23.5°C. and for growth 5.0°C. to 18.5°C. Burrows (1963) reported that the optimum growth of juvenile Pacific salmon falls within the narrow range of 10°C. to 15°C. Chapman (1938) observed that 452 of 1,000 king salmon fry died while being held in water of 19.5°C. to 20.5°C. even though the oxygen level was ample. At the same time, there were no deaths among king salmon fry held in water of the same source but having a lower temperature range (7.5°C. to 14.1°C.). On the basis of these data, lethal temperatures can be expected to occur in the Arcata pond during June,

July and August and poor growth conditions during May and September. Thus, from the standpoint of temperature alone salmonids could have been reared in the Arcata pond only from October through April during the study period.

According to Tarzwell (1958), salmonids usually are not found where the minimum dissolved oxygen concentration is less than 4 or 5 mg/l. Five mg/l are required for normal feeding and growth. At low temperatures salmonids have been known to survive short periods at 1.5 to 2.0 mg/l but these levels are not satisfactory for continual existence. Ellis, et al. (1946) stated that 3.0 mg/l is approximately the lethal point for freshwater fishes at summer temperatures. Davidson, et al. (1959) found that silver salmon fingerlings could survive at 2.0 mg/l dissolved oxygen but ate sluggishly and lost weight. At 3.0 mg/l they fed as well as fish held in well aerated waters. Hermann, et al. (1962) reported that food consumption by juvenile silver salmon declined with reduction of dissolved oxygen concentration of 8.3 to 6.0 and 5.0 mg/l and declined more sharply with further reduction of oxygen concentration. Besides the direct effect of low dissolved oxygen levels, most fishes are susceptible to concentrations of toxic materials which they can tolerate at higher dissolved oxygen levels (McKee and Wolf, 1963). Thus, in terms of minimum dissolved oxygen concentrations the Arcata oxidation pond was not suitable for the rearing of salmonids. Minimum concentrations observed in the months of January, February, July, October, November and December, 1960

and May, 1961 were within the tolerable oxygen range for salmonids, however, as mentioned previously, there is no assurance that lower values did not occur during these months.

Although no references were found relating to salmonids, it is known that supersaturation of dissolved oxygen can be detrimental to fish. For example, in Westlake Park in Los Angeles fish died when oxygen reached 300 per cent of saturation (Anon., 1938). The kill was attributed to oxygen bubbles coating the gills. In the present study saturation values of 256 per cent were observed.

There are other features of the Arcata pond besides temperature and dissolved oxygen that would affect the pond's suitability as a rearing area for salmonids or other fishes. For example, McKee and Wolf (1963) found that pH values below 5 and above 9 may exert a direct lethal effect upon fishes. Within these limits a change in pH may increase or decrease the toxicity of various chemicals to fishes. The toxicity of metals, cyanides, and sulfides may be increased by a decrease in pH while the toxicity of ammonia is greater at higher pH values. In the Arcata pond, pH values were observed to exceed 9.0 during the summer months and this may have been sufficient to be lethal to some fishes. Ammonia concentrations may have been high enough, perhaps often, to kill many kinds of fishes when the pH of the water was around the maximum observed. The concentration of synthetic detergents also may have been high enough to be lethal to many fishes.

During the study the pond effluent was nearly always toxic to young salmonids.

It is concluded, therefore, that the Arcata sewage oxidation pond was unsuitable during the study period as a rearing area for most species of fish.

# VII SUMMARY

1. The specific objective of this study was to gain background information concerning certain chemical and physical features of the Arcata, California, sewage oxidation pond in order to assess waste treatment performance of the pond relative to future operational changes. Secondary objectives of the study were to evaluate present waste treatment performance of the Arcata pond and to determine its ability to support fishlife.

2. The study was conducted during the period September, 1959 through November, 1961.

3. The City of Arcata is situated on the California coast, approximately 290 miles north of San Francisco. The climate of the area is typically maritime and characterized by high humidity and moderate temperatures. Waste treatment facilities consisted of a conventional clarifier for primary treatment and an oxidation pond which provides secondary treatment. The facilities were designed to serve a population of 15,000 although at the time of the study the sewered population was approximately 9,000.

4. The oxidation pond is located adjacent to the primary treatment facility on a tidal flat. At its normal operating level the pond covered a surface area of 59 acres and had an average depth of 3 feet. Clarifier effluent entered the pond from a submerged pipe and the pond effluent was

discharged directly to Humboldt Bay.

5. Flows to the Arcata treatment facility consisting of domestic sewage and waste water were found to range from 0.342 to 0.65 m.g.d. Both diurnal and weekly flow patterns were evident. Annual metered flows to the Arcata pond were found to range from 0.342 to 5.514 m.g.d. Flows in excess of 3,000 g.p.m. (4.32 m.g.d.) were attributed to infiltration of storm water into the sewage collection system. The excess flows were bypassed directly to the pond without being metered. As a consequence, actual flows to the pond during and following storms are higher than reported.

6. Detentions of waste water in the Arcata pond ranged from 30 to 164 days.

7. The methods of sampling and analysis were generally in accordance with those outlined by the American Public Health Association.

8. The surface of the Arcata sewage oxidation pond showed a moderate daily uniformity of temperature. Differences among various points in the pond never exceeded 2.7°C. and in most instances were less than 1°C. Response to air temperature and solar radiation caused surface water temperatures at a single station to vary diurnally by as much as 8.3°C. Seasonally, surface water temperatures were found to range from 6.1°C. to 25.6°C.

9. Transparency of the Arcata pond as determined by Secchi disc readings was quite variable in both space and time. Differences among stations at any one time ranged from 3 to

65 cm. No consistent diurnal or seasonal pattern was evident. The highest value noted was 120 cm and the lowest was 17 cm. Algae abundance and distribution were two of the main factors influencing transparency readings.

10. Differences in pH among stations sampled within the same time interval were small. At no time were they found to exceed 1.28 units. Diurnal variations in pH also were small since they were never found to exceed 1.29 units. Seasonally, pH ranged from 6.6 to 9.62. During the summer months pH often exceeded 9.00 while during the rest of the year it remained below this value.

11. Differences in conductivity among stations sampled within the same time interval ranged from 8 to 1035 mmhos/cm. No general pattern of diurnal change was evident. Seasonally, a pattern of change was evident with the highest values found at the end of the dry season and the lowest values at the end of the wet season. During the study annual conductivity values at station H were found to range from 770 to 4255 mmhos/cm. Salt water intrusion from Humboldt Bay was indicated from samples having conductivity values above 2000 mmhos/cm. Comparing conductivity readings with simultaneous dissolved oxygen values further indicated that the salt water intrusion sometimes had an adverse effect on pond conditions by depressing the photosynthetic activity of algae.

12. Dissolved oxygen concentrations were found to be highly variable in the Arcata sewage oxidation pond. Differences in surface concentrations at various pond locations during the same time interval ranged from 0.1 to 13.3 mg/l whereas

vertical differences at a single location ranged from 0.1 to 9.4 mg/l. Diurnal differences in surface dissolved oxygen concentration were found to range from 1.7 to 20.5 mg/l. No distinct seasonal pattern was evident although throughout the study dissolved oxygen concentrations ranged from 0 to 23.1 mg/l. The predator-prey relationship of algae and zooplankton populations was found to be a major factor influencing the level of dissolved oxygen in the Arcata pond at a given moment. High dissolved oxygen levels were associated with high algal densities and low Daphnia densities. Conversely, low dissolved oxygen levels were associated with low algal densities and high Daphnia densities.

13. Differences in total and phenolphthalein alkalinity at various points in the Arcata pond during the same time interval ranged from 0.3 to 38.5 mg/l and 1.2 to 20.8 mg/l, respectively. Phenolphthalein alkalinity was found to follow a pronounced diurnal pattern, changing at times by as much as 42 mg/l. Diurnal ranges for total alkalinity were as much as 21 mg/l, although generally the differences were less than 4 mg/l. No distinct seasonal pattern in phenolphthalein alkalinity was evident. On the other hand, a pronounced seasonal pattern was evident in total alkalinity. Total alkalinity concentration gradually increased throughout the dry season to a maximum of 296 mg/l and then gradually decreased during the wet season to a low of 121 mg/l. This cyclic pattern is characteristic of many highly entrophic waters.

14. Nitrogen concentrations at the outfall ranged as follows: ammonia, 5.63 to 7.25 mg/l; organic, 4.30 to 11.28 mg/l; nitrate, 0.18 to 0.28 mg/l and nitrite, 0.033 to 0.080 mg/l. Nitrate and nitrite nitrogen values were low because algae readily utilize nitrogen in the form of ammonia and thus limit nitrification to that stage.

15. Pronounced diurnal and seasonal patterns were evident in the influent B.O.D. In general, the B.O.D. was accentuated during the daylight hours and depressed during the nocturnal hours. Diurnal B.O.D. values ranged from 36 to 101 mg/l during the wet season and 80 to 267 mg/l during the dry season. The diurnal pattern of the outfall B.O.D. was not as pronounced as the influent B.O.D. since the B.O.D. concentration was found to vary from 7 to 10 mg/l. The daytime B.O.D. values were generally higher than the nocturnal values due mainly to the response of motile algae to light. A pronounced seasonal pattern of change was not evident.

16. The Arcata sewage oxidation pond facility was found to provide secondary waste treatment comparable to conventional facilities as well as to other sewage oxidation ponds. Pond loadings ranged from 15 to 28 lbs./B.O.D. per surface acre per day and on an overall basis this was reduced by 86 per cent. In addition, the pond remained aerobic most of the time and thereby prevented development of obnoxious odors. Although not studied, it is reasonable to assume that phosphorus and nitrogen reductions were in excess of 80 and 90 per cent, respectively. Low winter temperatures had little

effect on pond performance.

17. The environment of the Arcata sewage oxidation pond was not suitable for the rearing of most species of fish.

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Appendix A.--Monthly climatological conditions with comparable data for September, 1959, to August, 1961, Eureka, California.a/

| Year Month | Air Temperature (°F.) Max. | Mean Max. | Mean | Min. | Mean Min. | | Mean Rainfall (inches) | | Mean Speed (MPH) | | Prevailing Direction | | Mean percent possible |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1959 | | | | | | | | | | | | | |
| Sept. | 69 | [illegible] | [illegible] | 46 | 52.4 | [illegible] | | | [illegible] | [illegible] | N | [illegible] | 61 |
| Oct. | 70 | [illegible] | | [illegible] | 49.5 | | | | | | | | [illegible] |
| Nov. | 73 | [illegible] | | | | | | | | | | | |
| Dec. | 66 | 55.5 | [illegible] | | | | | | [illegible] | | | | |
| 1960 | | | | | | | | | | | | | |
| Jan. | 65 | [illegible] | 48.5 | 30 | | | | 6.93 | 6.5 | 7.0 | S | SE | 32 |
| Feb. | 64 | [illegible] | 48.4 | 33 | [illegible] | [illegible] | [illegible] | 6.[illegible] | [illegible] | 7.7 | N | SE | 57 |
| Mar. | 70 | [illegible] | [illegible] | [illegible] | 45.5 | 49.1 | 8.33 | [illegible] | 7.2 | 7.1 | S | N | 30 |
| Apr. | 66 | 55.6 | 50.9 | 37 | 45.2 | 50.6 | 2.5 | 3.00 | 7.2 | 8.1 | N | N | 44 |
| May | 71 | 58.3 | 53.3 | 42 | 48.3 | 52.9 | 6.05 | 2.03 | 9.0 | 7.[illegible] | N | N | 53 |
| June | 69 | 58.8 | 54.5 | 45 | 50.1 | 55.6 | [illegible] | 0.80 | 7.1 | 7.[illegible] | [illegible]W | N | 58 |
| July | 63 | 58.3 | 54.3 | 47 | 50.3 | 56.4 | 0.0[illegible] | [illegible] | 6.1 | 6.[illegible] | N | N | 47 |
| Aug. | 64 | 59.[illegible] | [illegible] | 47 | 50.[illegible] | 52.0 | 0.0[illegible] | [illegible] | 6.2 | 5.7 | | | 51 |
| Sept. | 64 | [illegible] | | [illegible] | [illegible] | 56.2 | 0.03 | 0.88 | 5.1 | 5.[illegible] | | | |
| Oct. | 77 | [illegible] | | | [illegible] | | [illegible] | 2.65 | 5.5 | 5.6 | | | |
| Nov. | 66 | [illegible] | | | | | | [illegible] | [illegible] | | | | [illegible] |
| Dec. | 62 | 55.1 | [illegible] | | | | | | | | | | 58 |
| 1961 | | | | | | | | | | | | | |
| Jan. | 69 | 57.7 | 50.5 | 34 | 43.3 | | | | | | E | | 59 |
| Feb. | 67 | 56.2 | 50.2 | 36 | [illegible] | | 7.[illegible] | | [illegible] | | S | | 45 |
| Mar. | 63 | 54.3 | 49.7 | 32 | [illegible] | | 7.[illegible] | | 8.6 | | S | | 49 |
| Apr. | 63 | 54.7 | 49.2 | 36 | [illegible] | | 3.49 | | 8.2 | | E | | [illegible] |
| May | 64 | 56.9 | 52.5 | 43 | [illegible] | | 3.97 | | 7.7 | | NW | | |
| June | 73 | 60.5 | 56.4 | 48 | [illegible] | | 0.50 | | 7.0 | | NW | | |
| July | 64 | 60.8 | 56.7 | 49 | [illegible] | | 0.03 | | 5.8 | | | | 51 |
| Aug. | 68 | 61.2 | 57.2 | 50 | 53.1 | | 0.30 | | 5.0 | | | | 38 |

a/ U.S. Dept. Commerce, Weather Bureau ([illegible] 1961).

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Appendix B.--Metered inflow to the sewage oxidation pond from September, 1959, to August, 1961, Arcata, California.

| Year Month | Daily Inflow (m.g.) Max. | Min. | Mean | Range (m.g.) | Detention Period (Days)[a/] |
|---|---|---|---|---|---|
| 1959 | | | | | |
| Sept. | 0.816 | 0.462 | 0.606 | 0.354 | 139 |
| Oct. | 0.816 | 0.516 | 0.669 | 0.300 | 126 |
| Nov. | 0.792 | 0.582 | 0.683 | 0.210 | 123 |
| Dec. | 2.496 | 0.630 | 0.880 | 1.866 | 95 |
| 1960 | | | | | |
| Jan. | 2.916 | 0.720 | 1.374 | 2.196 | 61 |
| Feb. | 4.824 | 0.809 | 1.895 | 4.015 | 44 |
| Mar. | 4.049 | 0.864 | 1.947 | 3.185 | 43 |
| Apr. | 1.999 | 0.847 | 1.254 | 1.152 | 67 |
| May | 4.968 | 0.822 | 1.752 | 4.146 | 48 |
| June | 1.379 | 0.498 | 0.719 | 0.881 | 118 |
| July | 0.624 | 0.342 | 0.519 | 0.282 | 162 |
| Aug. | 0.588 | 0.427 | 0.512 | 0.161 | 164 |
| Sept. | 0.650 | 0.422 | 0.513 | 0.228 | 164 |
| Oct. | 0.648 | 0.444 | 0.517 | 0.204 | 162 |
| Nov. | 4.938 | 0.386 | 1.531 | 4.552 | 55 |
| Dec. | 5.262 | 0.972 | 1.903 | 4.290 | 44 |
| 1961 | | | | | |
| Jan. | 3.924 | 0.738 | 1.207 | 3.186 | 70 |
| Feb. | 5.514 | 1.350 | 2.768 | 4.164 | 30 |
| Mar. | 4.908 | 1.476 | 2.974 | 3.432 | 28 |
| Apr. | 4.140 | 0.948 | 1.560 | 3.192 | 54 |
| May | 4.788 | 1.028 | 2.116 | 3.760 | 40 |
| June | 1.638 | 0.684 | 0.922 | 0.954 | 91 |
| July | 0.768 | 0.516 | 0.646 | 0.252 | 130 |
| Aug. | 0.660 | 0.594 | 0.618 | 0.066 | 136 |

[a/] Based on displacement of normal operating volume of pond (84 m.g.) and assuming no short-circuiting.

Append[illegible].--Su[illegible] se[illegible] [illegible]x [illegible]empera[illegible]ion pond, [illegible]at s[illegible]ua, C [illegible]the

| Year Month | No. of daily obs.a/ | Mean (°C.) | [illegible] | [illegible] | [illegible]e (°C.) |
|---|---|---|---|---|---|
| 1960 | | | | | |
| May | 16 | 17.4 | | 14.4 | 6.7 |
| June | 30 | 20.6 | | 17.2 | 7.3 |
| July | 31 | 20.5 | | 17.8 | 5.5 |
| Aug | 31 | 19.4 | | 15.6 | 8.3 |
| Se | 24 | 18.2 | | 16.1 | 5.0 |
| [illegible] | 30 | [illegible].3 | | 12.8 | 8.5 |
| | 29 | [illegible].0 | | 8.9 | 6.7 |
| | 30 | [illegible].8 | | 6.1 | 4.5 |
| [illegible] | 14 | [illegible].4 | | 6.7 | 6.1 |
| [illegible]. | 16 | [illegible].8 | | 9.4 | 3.4 |
| Mar. | 31 | [illegible].4 | | 9.4 | 7.3 |
| Apr. | 30 | 14.2 | | 9.4 | 8.9 |
| May | 31 | 15.6 | 3 | 12.8 | 7.2 |
| June | 30 | 19.2 | 9 | 15.0 | 10.0 |
| July | 28 | 20.5 | 0 | 17.2 | 8.4 |
| Aug. | 3 | 18.2 | .4 | 17.2 | 1.7 |

a/ Refers only t[illegible]s. data.

Appendix D.--Secchi disc observations in the sewage oxidation pond, Arcata, California.

| Year<br>Month | No. Obs. | Max. (cm) | Mean (cm) | Min. (cm) | Range (cm) |
|---|---|---|---|---|---|
| 1960 | | | | | |
| Apr. | 15 | 79 | 40 | 28 | 51 |
| May | 8 | 53 | 51 | 46 | 7 |
| June | 25 | 64 | 43 | 33 | 31 |
| July | 37 | 76 | 54 | 28 | 48 |
| Aug. | 4 | 91 | 72 | 50 | 41 |
| Sept. | 10 | 90 | 61 | 43 | 47 |
| Oct. | 10 | 41 | 29 | 20 | 21 |
| Nov. | 3 | 32 | 26 | 17 | 15 |
| Dec. | 2 | 54 | 51 | 48 | 6 |
| 1961 | | | | | |
| Mar. | 12 | 60 | 54 | 40 | 20 |
| Apr. | 3 | 120 | 94 | 42 | 78 |
| May | 5 | 110 | 76 | 30 | 80 |
| June | 12 | 100 | 49 | 28 | 72 |
| July | 3 | 50 | 33 | 18 | 32 |
| Total | 151 | | | | |
| Mean | | | 50 | | |

Appendix E.--Surface hydrogen ion concentration (pH) in the sewage oxidation pond, Arcata, California.

| Year Month | Number Observations | Maximum | Mean | Minimum | Range |
|---|---|---|---|---|---|
| 1959 | | | | | |
| Sept. | 1 | - | 7.75 | - | - |
| Oct. | 5 | 7.75 | 7.68 | 7.60 | 0.15 |
| Nov. | 2 | 7.70 | 7.70 | 7.70 | 0 |
| Dec. | 3 | 7.64 | 7.61 | 7.60 | 0.04 |
| 1960 | | | | | |
| Jan. | 2 | 7.75 | 7.52 | 7.30 | 0.45 |
| Feb. | 49 | 8.88 | 8.06 | 7.45 | 1.43 |
| Mar. | 6 | 8.60 | 8.00 | 7.65 | 0.95 |
| Apr. | - | - | - | - | - |
| May | 24 | 7.5 | 7.3 | 6.6 | 0.9 |
| June | 71 | 9.45 | 8.01 | 7.30 | 2.15 |
| July | 51 | 9.51 | 9.07 | 8.61 | 0.90 |
| Aug. | 39 | 9.31 | 8.66 | 7.81 | 1.50 |
| Sept. | 17 | 8.94 | 8.29 | 7.28 | 1.66 |
| Oct. | 16 | 9.39 | 8.82 | 8.25 | 1.14 |
| Nov. | 44 | 8.92 | 8.13 | 7.35 | 1.57 |
| Dec. | 12 | 8.60 | 8.32 | 7.92 | 0.68 |
| 1961 | | | | | |
| Jan. | - | - | - | - | - |
| Feb. | 56 | 8.60 | 7.58 | 7.14 | 1.46 |
| Mar. | 17 | 8.69 | 7.48 | 7.19 | 1.50 |
| Apr. | 1 | - | 8.34 | - | - |
| May | 1 | - | 8.76 | - | - |
| June | 3 | 9.16 | 8.64 | 7.92 | 1.24 |
| July | 40 | 9.62 | 8.90 | 8.33 | 1.29 |
| Aug. | 13 | 8.12 | 7.73 | 7.42 | 0.70 |
| Total | 473 | | | | |
| Mean | | | 8.11 | | |

Appendix F.--Surface specific electrical conductance (conductivity) observations in the sewage oxidation pond, Arcata, California.

| Year Month | Number Observations | Conductivity in micromhos/cm. Maximum | Mean | Minimum | Range |
|---|---|---|---|---|---|
| 1959 | | | | | |
| July | 5 | 3845 | 3346 | 2815 | 1030 |
| Aug. | 13 | 4180 | 3591 | 2857 | 1323 |
| Sept. | 1 | - | 4255 | - | - |
| Oct. | 5 | 3845 | 3296 | 3035 | 810 |
| Nov. | 5 | 3035 | 2825 | 2600 | 435 |
| Dec. | 1 | - | 2275 | - | - |
| 1960 | | | | | |
| Jan. | 2 | 2275 | 2148 | 2021 | 254 |
| Feb. | 49 | 1088 | 990 | 920 | 168 |
| Mar. | 5 | 795 | 770 | 758 | 37 |
| June | 2 | 855 | 851 | 847 | 8 |
| Total | 88 | | | | |
| Mean | | | 2290 | | |

Appendix G.--Kemmerer depth dissolved oxygen concentrations and saturations in the sewage oxidation pond, Arcata, California.

| Year Month | No. Obs. | Dissolved Oxygen Concentration (mg/l) Max. | Min. | Range | Per Cent Saturation Max. | Min. |
|---|---|---|---|---|---|---|
| 1959 | | | | | | |
| Sept. | 1 | 2.4 | 2.4 | -- | 27.3 | 27.3 |
| Oct. | 6 | 3.7 | 1.3 | 2.4 | -- | 13.1 |
| Nov. | 18 | 4.8 | 0.7 | 4.1 | 45.5 | -- |
| Dec. | 11 | 6.8 | 2.0 | 4.8 | 57.7 | -- |
| 1960 | | | | | | |
| Jan. | 3 | 9.7 | 6.6 | 3.1 | 81.3 | 54.5 |
| Feb. | 53 | 19.2 | 11.1 | 8.1 | 175.8 | 98.0 |
| Mar. | 7 | 9.7 | 2.1 | 7.6 | 91.1 | 19.0 |
| Apr. | 4 | 10.9 | 0.8 | 10.1 | 102.3 | -- |
| May | 40 | 10.2 | 0.8 | 9.4 | 109.1 | 8.1 |
| June | 65 | 23.1 | 0.0 | 23.1 | 256.1 | 0.0 |
| July | 60 | 18.6 | 5.9 | 12.7 | 208.5 | 64.1 |
| Aug. | 81 | 22.7 | 0.0 | 22.7 | 256.2 | 0.0 |
| Sept. | 33 | 10.6 | 0.0 | 10.6 | 113.1 | 0.0 |
| Oct. | 31 | 21.7 | 8.0 | 13.7 | 218.1 | 81.8 |
| Nov. | 51 | 20.0 | 4.1 | 15.9 | 184.7 | 38.8 |
| Dec. | 12 | 19.9 | 14.0 | 5.9 | 167.6 | 120.1 |
| 1961 | | | | | | |
| Jan. | -- | -- | -- | -- | -- | -- |
| Feb. | 58 | 20.2 | 1.7 | 18.5 | 191.6 | 15.3 |
| Mar. | 26 | 20.4 | 0.2 | 20.2 | 198.0 | 1.8 |
| Apr. | 34 | 13.7 | 0.6 | 13.1 | 134.3 | 6.3 |
| May | 49 | 16.8 | 4.7 | 12.1 | 167.2 | 44.3 |
| June | 31 | 19.9 | 2.5 | 17.4 | 222.6 | 25.9 |
| July | 44 | 21.3 | 0.7 | 20.6 | 251.4 | 7.8 |
| Aug. | 13 | 3.7 | 0.1 | 3.6 | 39.0 | 1.0 |
| Total | 751 | | | | | |

Appendix H.--Surface alkalinity observations in the sewage oxidation pond, Arcata, California.

| Year Month | Phenolphthalein Alkalinity (mg/l $CaCO_3$) No. Obs. | Max. | Mean | Min. | Range | Total Alkalinity (mg/l $CaCO_3$) No. Obs. | Max. | Mean | Min. | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| 1960 | | | | | | | | | | |
| June | 20 | 38.2 | 24.2 | 13.5 | 24.7 | 24 | 206.0 | 168.2 | 133.8 | 72.2 |
| July | 9 | 29.2 | 25.7 | 15.4 | 13.8 | 9 | 183.5 | 179.1 | 174.5 | 9.0 |
| Aug. | 10 | 34.8 | 26.3 | 14.0 | 20.8 | 18 | 229.7 | 213.6 | 181.0 | 48.7 |
| Sept. | 3 | 18.5 | 15.5 | 13.1 | 5.4 | 13 | 296.0 | 248.2 | 223.0 | 73.0 |
| Oct. | 3 | 34.0 | 33.0 | 31.5 | 2.5 | 8 | 269.0 | 253.8 | 222.5 | 46.5 |
| Nov. | 21 | 33.0 | 17.4 | 6.1 | 27.9 | 31 | 276.7 | 249.0 | 205.4 | 71.3 |
| Dec. | 4 | 11.2 | 9.1 | 4.9 | 6.3 | 12 | 170.0 | 166.2 | 147.1 | 22.9 |
| 1961 | | | | | | | | | | |
| Jan. | 0 | -- | -- | -- | -- | 0 | -- | -- | -- | -- |
| Feb. | 0 | -- | -- | -- | -- | 26 | 153.8 | 141.3 | 125.7 | 28.1 |
| Mar. | 1 | -- | 7.0 | -- | -- | 15 | 153.3 | 136.2 | 121.0 | 32.3 |
| Apr. | 1 | -- | 3.8 | -- | -- | 1 | -- | 132.5 | -- | -- |
| May | 1 | -- | 17.4 | -- | -- | 3 | 145.0 | 142.6 | 140.6 | 4.5 |
| June | 1 | -- | 12.6 | -- | -- | 3 | 163.3 | 151.3 | 142.5 | 20.8 |
| July | 40 | 47.1 | 21.4 | 5.1 | 42.0 | 40 | 198.3 | 179.5 | 172.8 | 25.5 |
| Aug. | 0 | -- | -- | -- | -- | 13 | 210.0 | 205.2 | 198.8 | 11.2 |
| Total | 114 | | | | | 216 | | | | |
| Mean | | | 21.2 | | | | | 188.2 | | |

Appendix I.--Biochemical oxygen demand observations (in mg/l) at the sewage treatment plant clarifier, Arcata, California.

| Date | Time | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1600 | 1900 | 2200 | 0100 | 0400 | 0700 | 1000 | 1300 |
| 8-10-60 | 117 | -- | -- | -- | -- | -- | -- | -- |
| 8-17-60 | 118 | -- | -- | -- | -- | -- | -- | -- |
| 8-24-60 | 107 | -- | -- | -- | -- | -- | -- | -- |
| 10- 2-60 | -- | -- | -- | -- | -- | -- | -- | 44 |
| 10-15-60 | 153 | -- | -- | -- | -- | -- | -- | -- |
| 10-21-60 | -- | -- | -- | -- | -- | -- | 100 | -- |
| 3- 7-61 | 91 | -- | -- | -- | -- | -- | -- | -- |
| 3-14-61 | -- | -- | -- | -- | -- | -- | 79 | -- |
| 3-22-61 | 60 | 101 | 65 | -- | -- | -- | -- | -- |
| 3-23-61 | -- | -- | -- | 36 | -- | -- | 54 | 75 |
| 4- 5-61 | 184 | 161 | 141 | -- | -- | -- | -- | -- |
| 4- 6-61 | 161 | -- | -- | 99 | 50 | 32 | 121 | 151 |
| 4-26-61 | -- | 106 | 124 | -- | -- | -- | -- | -- |
| 4-27-61 | 132 | 106 | -- | 56 | 26 | 84 | 138 | 151 |
| 7-28-61 | -- | 162 | 193 | -- | -- | -- | -- | -- |
| 7-29-61 | 267 | 191 | -- | 112 | 80 | 90 | 174 | 235 |

Appendix J.--Biochemical oxygen demand observations (in mg/l) at station H, in the sewage oxidation pond, Arcata, California.

| Date | Time | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1600 | 1900 | 2200 | 0100 | 0400 | 0700 | 1000 | 1300 |
| 8-17-60 | 7 | -- | -- | -- | -- | -- | -- | -- |
| 8-19-60 | 8 | -- | -- | -- | -- | -- | -- | -- |
| 8-24-60 | 7 | -- | -- | -- | -- | -- | -- | -- |
| 10- 2-60 | -- | -- | -- | -- | -- | -- | -- | 5 |
| 10-15-60 | 9 | -- | -- | -- | -- | -- | -- | -- |
| 3- 7-61 | 16 | -- | -- | -- | -- | -- | -- | -- |
| 3-14-61 | -- | -- | -- | -- | -- | -- | 9 | -- |
| 6-23-61 | 16 | 14 | 10 | -- | -- | -- | -- | -- |
| 6-24-61 | 20 | -- | -- | 10 | 10 | 11 | 12 | 14 |
| 7-14-61 | -- | 23 | 18 | -- | -- | -- | -- | -- |
| 7-15-61 | -- | -- | -- | 16 | 16 | 20 | 22 | -- |
| 7-22-61 | -- | 24 | 20 | -- | 16 | 28 | 24 | -- |
| 7-23-61 | -- | -- | -- | 23 | 27 | -- | -- | -- |
| 8- 2-61 | -- | -- | 14 | -- | -- | -- | -- | -- |
| 8- 3-61 | 22 | -- | 20 | -- | 15 | -- | 19 | -- |